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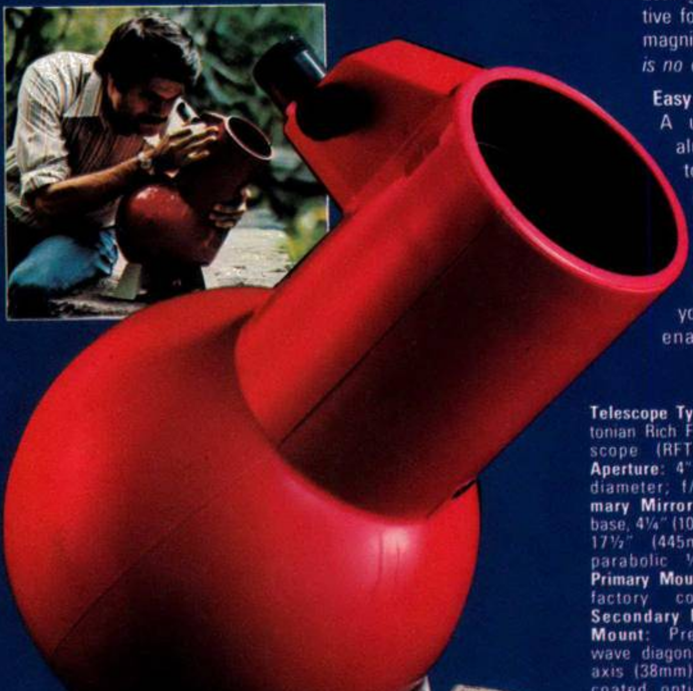

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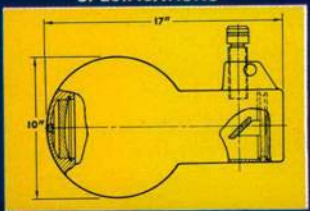

Telescope Type: Newtonian Rich Field Telescope (RFT). **Clear Aperture**: 4" (102mm) diameter; f/4.4. **Primary Mirror**: Pyrex® base, 4¼" (108mm) dia. 17½" (445mm) F.L. parabolic ⅛ wave. **Primary Mount**: Fixed, factory collimated. **Secondary Mirror & Mount**: Pre-aligned ⅛ wave diagonal 1½" minor axis (38mm) mounted to coated optical window. **Eyepiece**: 1¼" O.D., 28mm F.L. compound Achromatic. **Power**: 16X with above eyepiece. Other eyepieces or optional Barlow lens may be used to increase power. **Field of View**: 3.0° with eyepiece supplied. **Focusing**: Smooth, posi-grip, rubber roller focusing (25 feet to infinity). **Telescope Body**: Special, high-impact plastic. **Dimensions**: Length: 17" (432mm); Sphere dia.: 10" (254mm). **Weight**: 8.4 lbs. (3.8kg) without stand. Stand weight 2 lbs. (0.9kg).

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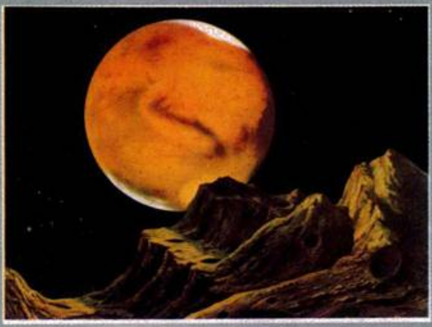

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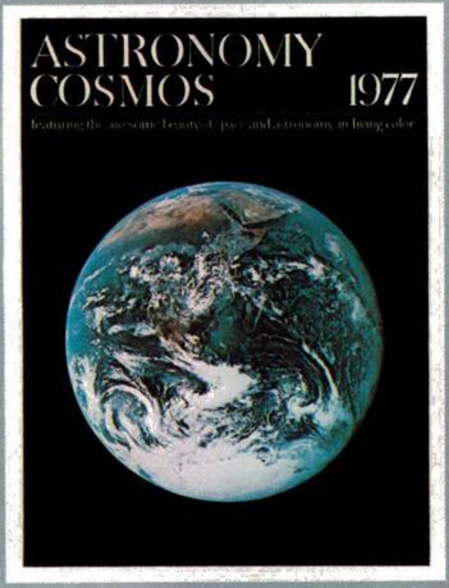
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Cover

As humanity expands into space, planets formerly hostile to life will be tamed. Our own planet's desolate regions will be first, with climate brought under control, rain brought to desert regions, and sunlight directed where needed by giant space mirrors. The moon, devoid of atmosphere since its formation, will be given air, water, weather and luxurious cities —perhaps as a playground for astronauts on leave from duty. ASTRONOMY's cover shows that future: The inhabited moon hangs in the sky above a lifesaving storm-abatement operation using a giant "soletta" space mirror to abort a tropical storm before it can do damage. As the evening shuttle from the space colonies descends for landing at Singapore Municipal spaceport (one of the world's leading interplanetary terminals), lights of the lunar cities shine on the dark side of the moon — at least from the areas where lunar clouds don't obscure them. Artwork by Mark Paternostro.

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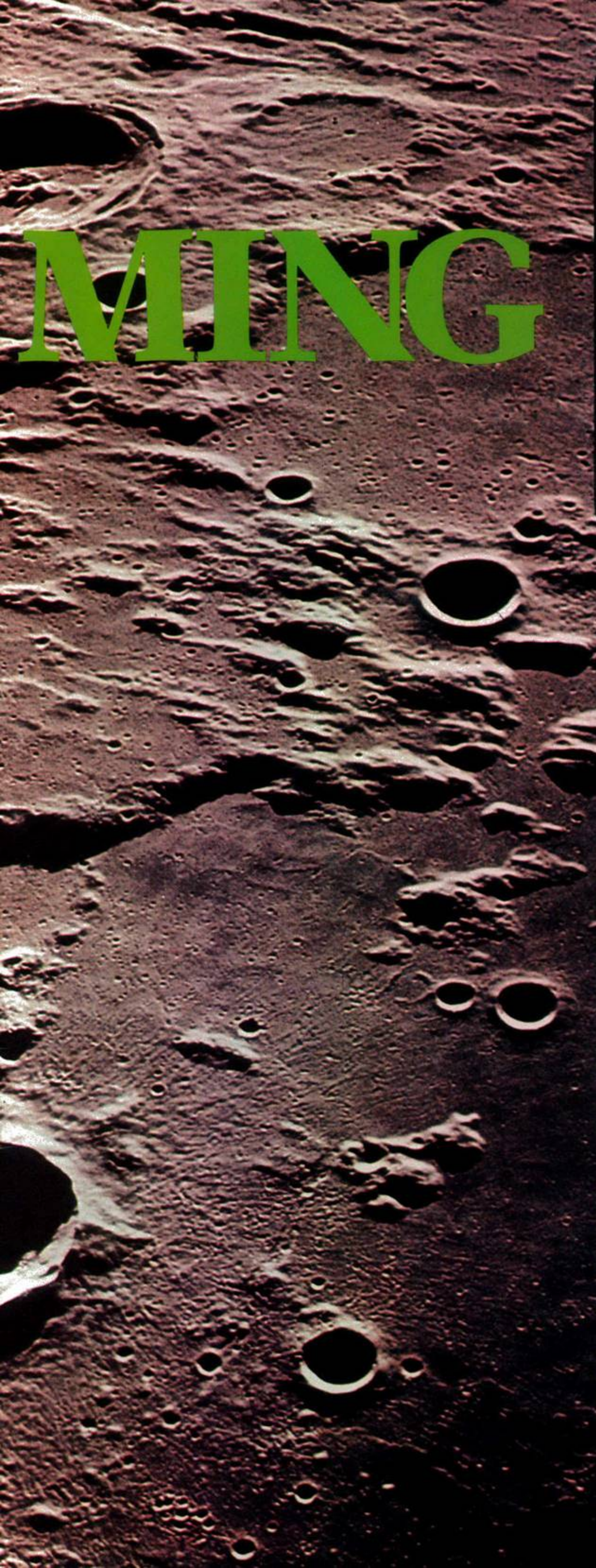


NASA photograph

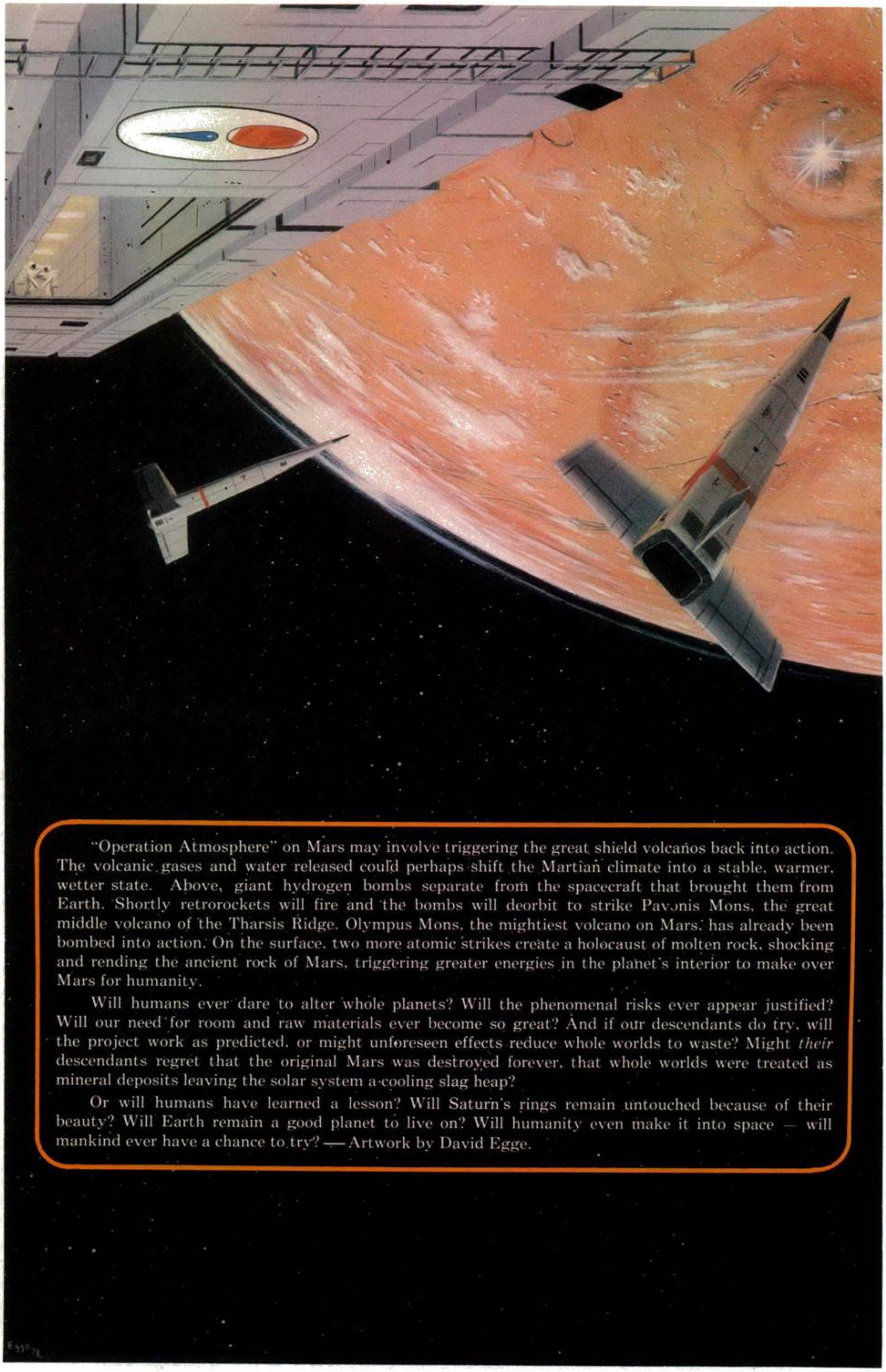
by
James Oberg

Philosophers and anthropologists mark the beginnings of human intelligence at the point in dim prehistory when human beings began to deliberately alter their environment, rather than passively accepting physical hardship as a natural occurrence. After that breakthrough, the march from scraped animal hides and campfires to spacesuits and life support systems was only one of technology, not concept.

For several decades, space prophets have forecast reshaping of other worlds to satisfy human physical needs. Massive planetary engineering — *terraforming* — is a long way from lighting a fire to warm a cave, but it's an extension of the same basic theme.

These visionaries suggest that through use of engineering skills and energies of the future, we will be able to transform hostile worlds into comfortable human living areas. Even if it's possible to accomplish such feats, critics may ask if they are justifiable. Will this practice of remodeling planets be an important activity of the 21st, 25th or 30th century?

We have already demonstrated our ability to change local — even global — environments on Earth. Meteorologists consider techniques of weather control in an age when human industrial and land clearing activities have already altered natural balances.



"Operation Atmosphere" on Mars may involve triggering the great shield volcanos back into action. The volcanic gases and water released could perhaps shift the Martian climate into a stable, warmer, wetter state. Above, giant hydrogen bombs separate from the spacecraft that brought them from Earth. Shortly retrorockets will fire and the bombs will deorbit to strike Pavonis Mons, the great middle volcano of the Tharsis Ridge. Olympus Mons, the mightiest volcano on Mars, has already been bombed into action. On the surface, two more atomic strikes create a holocaust of molten rock, shocking and rending the ancient rock of Mars, triggering greater energies in the planet's interior to make over Mars for humanity.

Will humans ever dare to alter whole planets? Will the phenomenal risks ever appear justified? Will our need for room and raw materials ever become so great? And if our descendants do try, will the project work as predicted, or might unforeseen effects reduce whole worlds to waste? Might *their* descendants regret that the original Mars was destroyed forever, that whole worlds were treated as mineral deposits leaving the solar system a cooling slag heap?

Or will humans have learned a lesson? Will Saturn's rings remain untouched because of their beauty? Will Earth remain a good planet to live on? Will humanity even make it into space — will mankind ever have a chance to try? —Artwork by David Egge.

The cause and effect of our terrestrial climate is still poorly understood. Rainfall is affected by things such as humidity, aerosols, dust and land reflectivity. All types of winds, from zephyrs to hurricanes, depend on solar energy input, surface waters and landforms — and tornados have some sort of connection with electrostatic and ball lightning phenomena. Sunlight on a surface depends on geological, astronomical and meteorological conditions.

Humans are altering the balance of nature, deliberately or not. Where the causal relationships are unknown, mysterious and sometimes damaging changes can occur.

Considering our state of ignorance about the basic mechanics of our terrestrial climate, it may seem presumptuous to entertain sweeping visions of planetwide engineering. But there is no holding back; the first world to be terraformed by human activity will be Earth itself. Hopefully, our home planet will survive our unwitting experimentation.

Entire continents may someday have their rainfall and wind patterns modified to improve agriculture, extend human comfort and promote industrial convenience. More than weather, even climate itself may be modified for the "better" — once that term can be quantified and agreed on.

Terrestrial climate control and modification techniques will be the first step in learning how to alter the ecologies of entire worlds beyond Earth. With a set of well understood tricks-of-the-trade, and specialized tools developed for use on alien worlds, future planetary engineers will be able to carry out what we can only dream of today:

- evaporate the clouds of Venus, spin up the retrograde planet, cool it, and allow oceans to form;
- make rain fall again on Mars, turning the red skies dark blue and tinging the red rocks with the green of lichens;
- give an atmosphere to Earth's barren moon, as an aid to surface transportation, as an experiment, or as an esthetic monument to "mankind's giant leap";
- dismantle the outer planets, using their hydrogen as rocket fuel and their rocky cores as material for a dozen new Earths;
- collect comets, asteroids and interplanetary dust — raw material for housing billions of our not-so-remote descendants.

These visions of future planetary modifications are breathtaking. But other futurologists disagree with the scenario, the assumptions and the projected outcome. They foresee a different future in which planets as we know them today would no longer be needed for human habitation, except perhaps as natural parks, wildlife sanctuaries and sentimental monuments to human origins.

NASA photograph

Initially, in this alternate vision, people would move out into artifical habitats — space colonies — which would spin to produce a simulacrum of gravity, *ersatz gravity*. Within a century or two, anticipated breakthroughs in physics would allow engineers to construct space platforms dozens of miles across using great machines to generate real *artificial gravity*.

Rock and soil from hard planets would be used in thin topsoil layers for esthetic or ecological reasons. These platforms in space, a million or a billion miles from the place Earth once was, would have powers of gravity and tamed stellar energy to last for millions of years. They would become the dwelling places of all but a tiny portion of the human race 1,000 years hence.

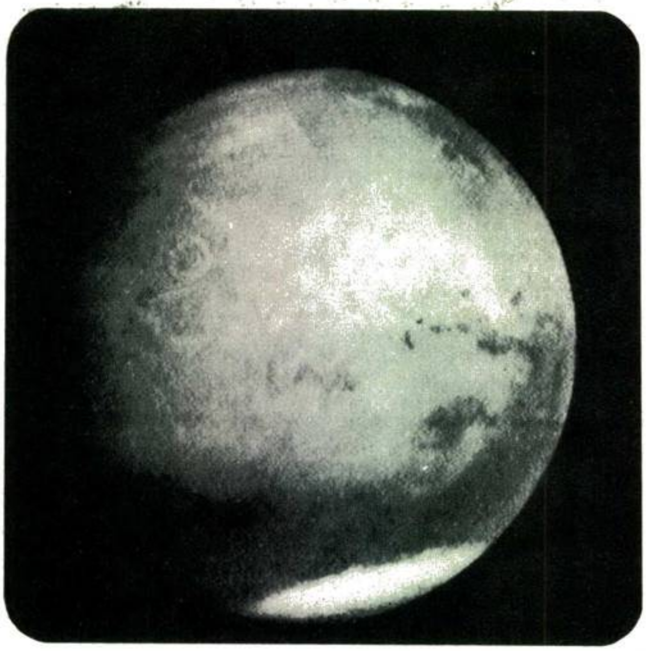
Let's look at these futures. Let's examine the proposed techniques of the profession of terraformers, of planetary engineers. Don't look in the "help wanted" ads or in college curriculum guides, since we are a century ahead of our time. But try to imagine . . . .

The Search for a Lever

Planets, without human intervention, seem to go through major climate changes by themselves. Often they seem to have leaped from one stable regime to another, perhaps in centuries or less. On Earth, ice ages are an example; on Mars, the dead river gulleys hint at another; on Venus, the strangling atmosphere may belie a more hospitable past in which oceans covered much of the planet and were the habitat of living creatures.

Although these changes may have been brought about by tremendous variations in solar output, or by interstellar dustclouds passing through the solar system (blocking a large fraction of sunlight), or by random collisions between solar system objects, many planetologists suspect that the shifts came about by some minor triggering action which modulated the great natural energy flux on each world.

Like Archimedes, who boasted that he could move the world with a lever if given a place to stand (and a long enough lever!), planetary engineers



NASA photograph

of the future will need to seek the ecological instability — the fulcrum and the lever which, when activated, will move a planetary biosphere — the kind of subtle change that may trigger terrestrial ice ages.

Just as a tiny tap can dislodge a huge teetering boulder, by finding those sensitive points it may be possible with relatively little effort to create planetary alterations such as:

- changing a planet with fast growing organisms whose specially tailored biological processes rapidly shift the former balance;
- "importing" light element volatiles from passing carbonaceous chondrite asteroids or water comets;
- changing the length of a planet's day;
- modifying the *insolation* (incoming sunlight) with giant mirrors or manmade obscuring dustclouds;
- modulating atmospheric transparency — indeed an entire planetary climate — by controlling ocean evaporation with a few well placed oil slicks, or finding ways to control devastating duststorms by trapping particulates on the surface, perhaps with plants.

Other terraforming projects may require less delicate tools — perhaps a brute force approach which might stagger the 20th century mind! Imagine building a planet from space debris, and then dispersing the heat of the new planetary crust melted during "assembly". Perhaps humans will disintegrate Saturn and distill from it the elements needed for human progress. There may come a time when the energies needed to move Neptune's moon Triton into orbit around Venus or Mercury will be available. There could be prospecting expeditions to the giant cloud of comets that circles our sun hundreds of billions of miles beyond sunless wastes beyond Pluto. Or there may be engineering to take an icy world like Ganymede, melt its surface, and then construct a solid surface suitable for comfortable habitation.

A New Mars for the Old Mars

Mars glitters in the human imagination even more brilliantly than it does in the night sky. It has already played a critical role in developing the concept of terraforming and will play an even more important role when terraforming moves from theory to practice.

The idea of terraforming originated from a mistake. At the beginning of this century, Percival Lowell "discovered" canals on Mars. He imagined that they were part of a massive planetwide irrigation system built to save the Martians as their small cold planet dried up. As the harsh conditions on Mars became better known, philosophers had difficulty imagining anything resembling a human being existing under Martian conditions. Lowell rejected this philosophical dead end. His Martian men were attempting to alter the whole ecology of their planet to fit their physical needs; they were conducting planetary engineering.

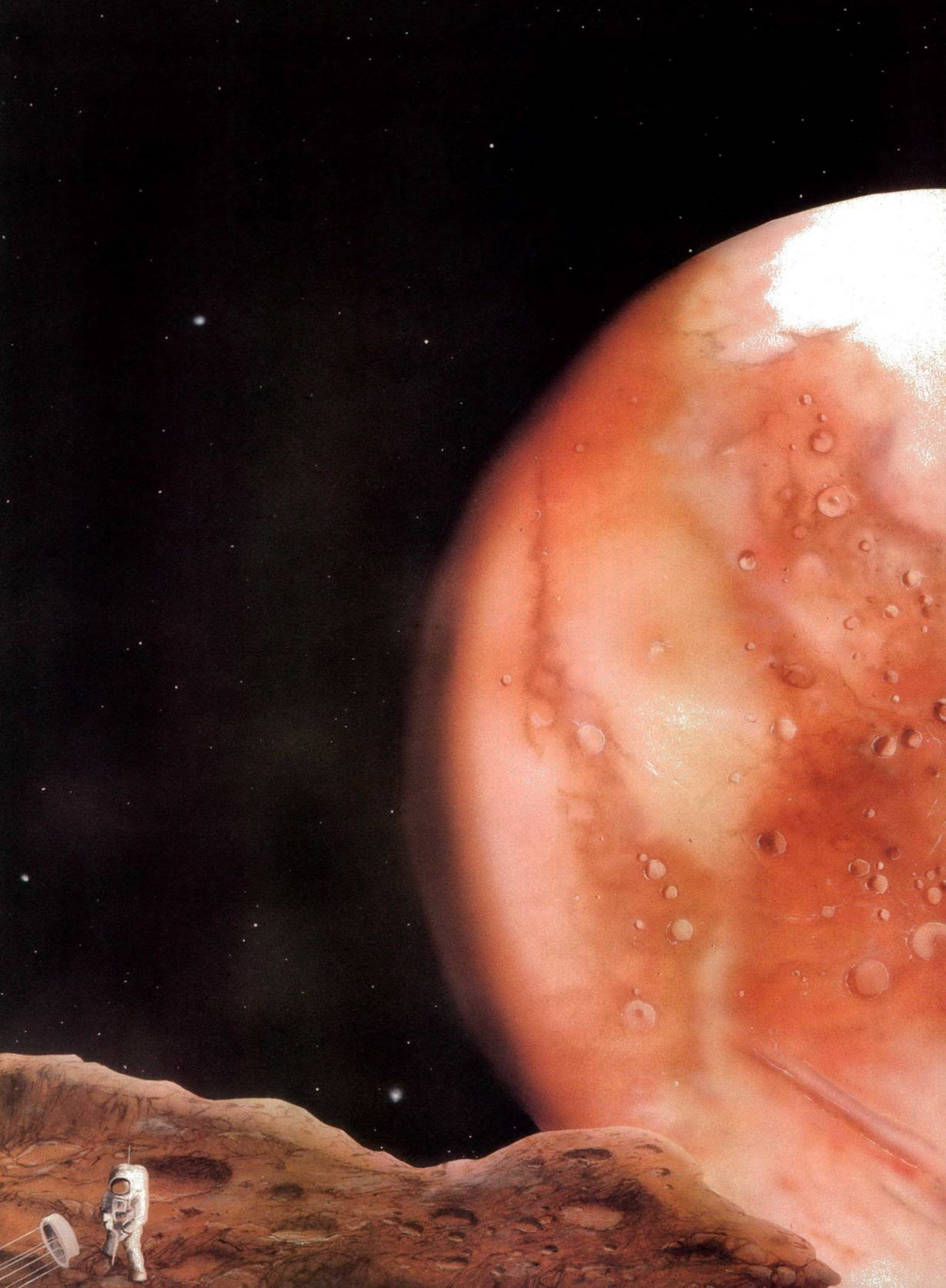
Lowell, with his vivid imagination, failed to establish the reality of his canals. But he produced something far more important — the concept of terraforming.

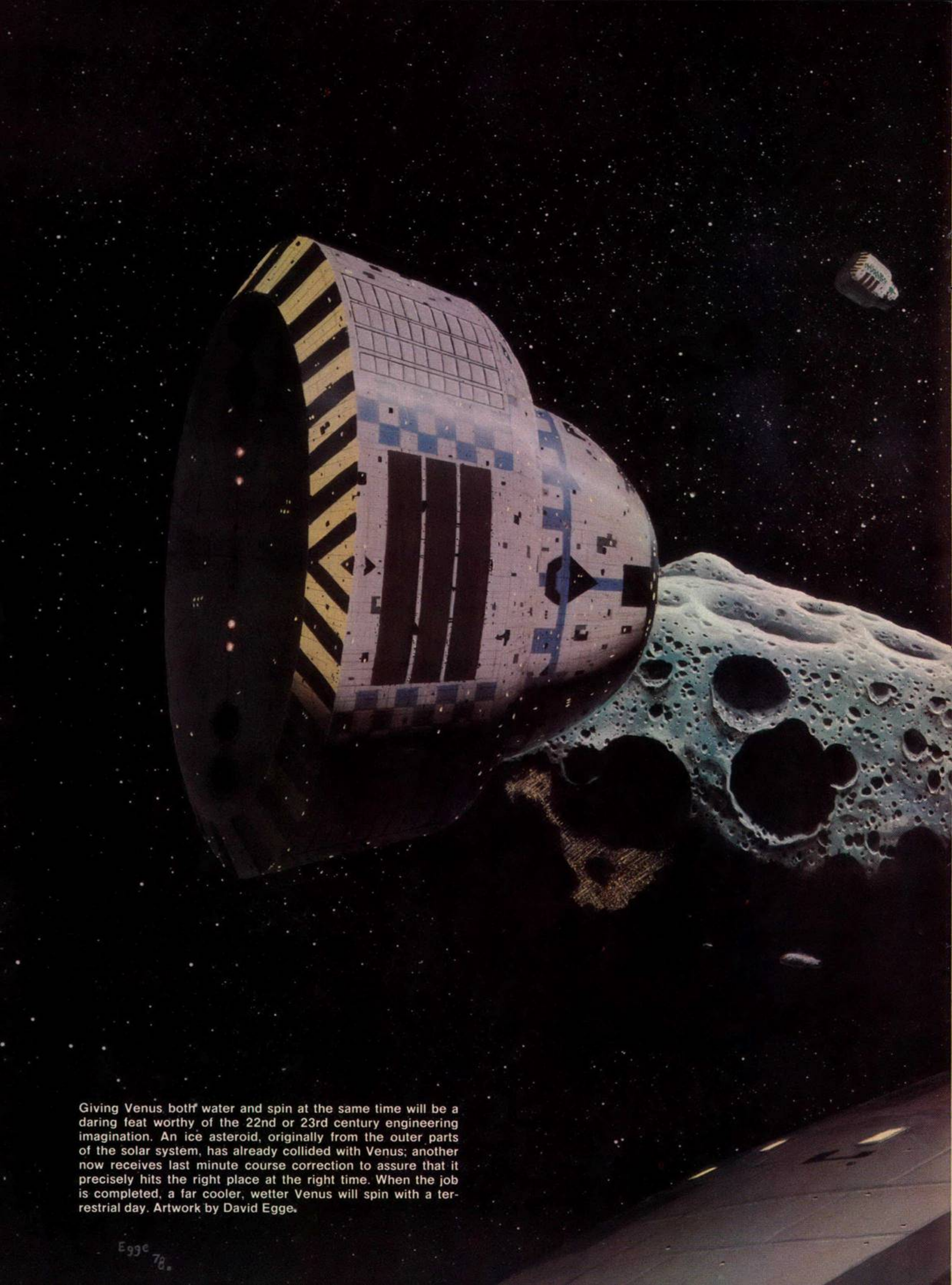
Since then, science fiction writers have been playing around with the idea of terraforming Mars. It was not dying Martians but immigrating Earthmen who, in Arthur C. Clarke's **Sands of Mars**, engineered an atmospheric buildup program. Clarke's acclimatized humans could stand outside briefly without oxygen masks — but the humans had to adjust physically to the thin air as, indeed, they have in such places as the high Andes and Tibet on Earth. A quarter century later, author Jerry Pournelle wrote of a project involving the detonation of nuclear bombs inside Martian volcanos to trigger the outgassing of a thicker atmosphere.

During the Viking missions in 1975-76, NASA's Ames Research Center sponsored a special research effort devoted to terraforming Mars. The result of the study was published in the NASA pamphlet, **On the Habitability of Mars: an Approach to Planetary Ecosynthesis**.

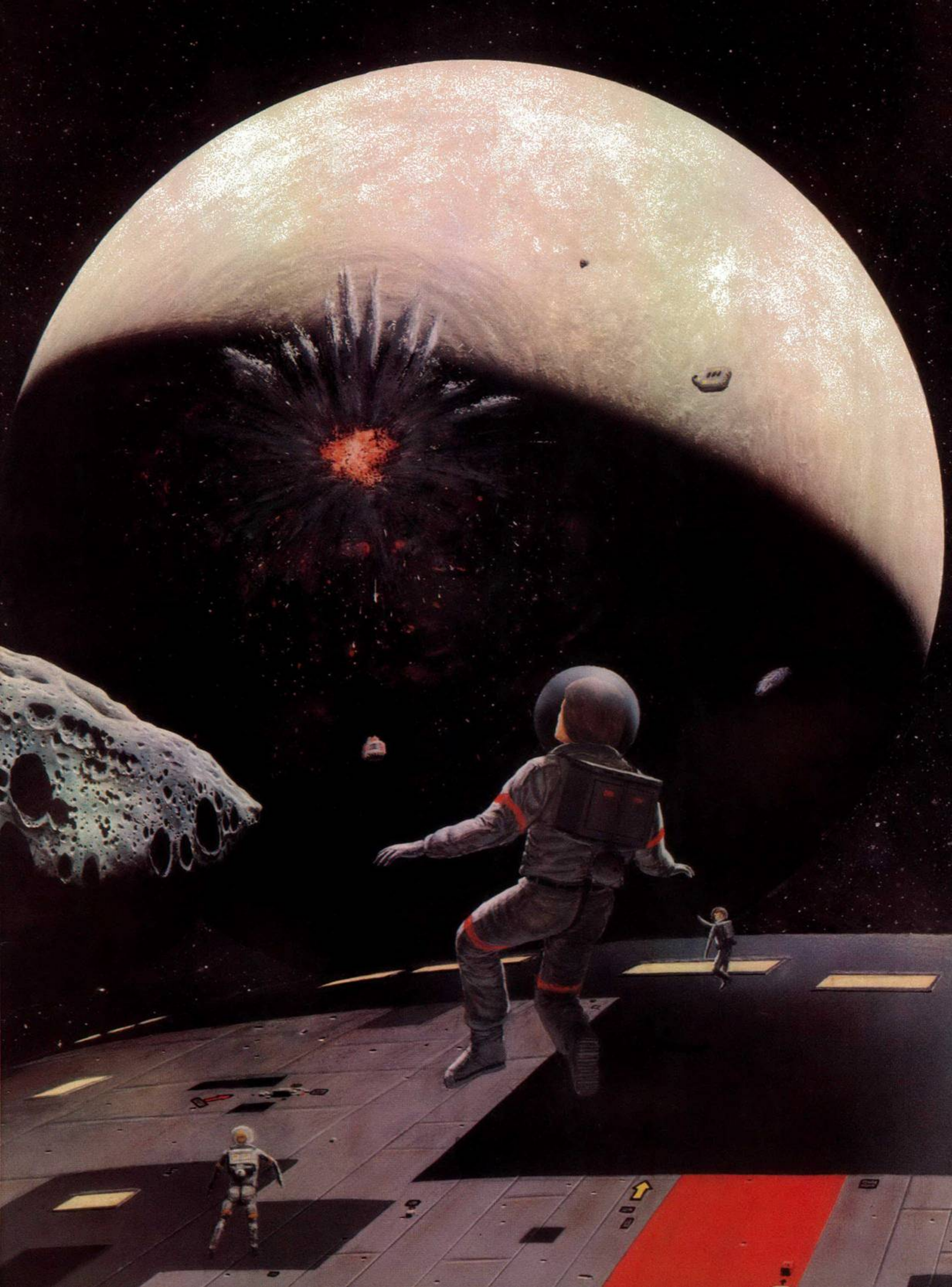
What would be required for the creation of a human supporting ecosphere on today's Mars? Compared to even the most hostile environments on Earth, such as the dry Antarctic valleys where the soil can be absolutely sterile, Mars is colder, drier, more airless, and more irradiated by lethal ultraviolet radiation. A human being suddenly turned out unprotected on Mars would gasp his last breath in the near vacuum. His feet would begin to freeze, although there would be little heat loss elsewhere. The ultra-

Mars may be the first target of terraformers. Landing on Phobos early in the next century, an astronaut gathers samples preliminary to the job of remaking the Martian atmosphere. Because Phobos material is so dark, if it were shot from orbit down to the polar cap of Mars, the darkened snow and ice would absorb more solar energy. With a thicker atmosphere from the melted caps, the present dry, cold climate regime of Mars might be broken: the beginning of making Mars a planet for humanity. Artwork by Leroy Williams.





Giving Venus both water and spin at the same time will be a daring feat worthy of the 22nd or 23rd century engineering imagination. An ice asteroid, originally from the outer parts of the solar system, has already collided with Venus; another now receives last minute course correction to assure that it precisely hits the right place at the right time. When the job is completed, a far cooler, wetter Venus will spin with a terrestrial day. Artwork by David Egge.



D.Beck

violet flux would begin a sunburn from which he would not live to suffer. Consciousness would fade with lack of oxygen. The corpse could take a million years to disappear, as first all the water sublimed out, and then the mummified flesh and bones were eroded ever so slowly by the soft Martian sandstorm.

There is neither free oxygen nor significant airborn water on Mars; even its air pressure is only one percent that of Earth. Ordinary Earth plants would be killed within minutes by the ultraviolet light. Yet the NASA study suggested that a tailored form of Earth life might be able to survive unprotected on Mars — even grow and reproduce. That biological tool might provide one lever in the delicate ecological system which could move that entire world closer to where we want it to be.

But first the key ingredients of temperature and air pressure must be considered. If the planet were warmer, the carbon dioxide in the polar caps would evaporate into an atmosphere perhaps 1/10 as thick as that of Earth. If the atmosphere were a lot thicker than it is now, various heating mechanisms would raise planetary temperatures, melt much of the icecaps and permafrost, and create a more benign environment.

The relationship is circular. Each undesirable factor (very cold, and nearly airless) supports the other. How can terraforming break into this closed loop?

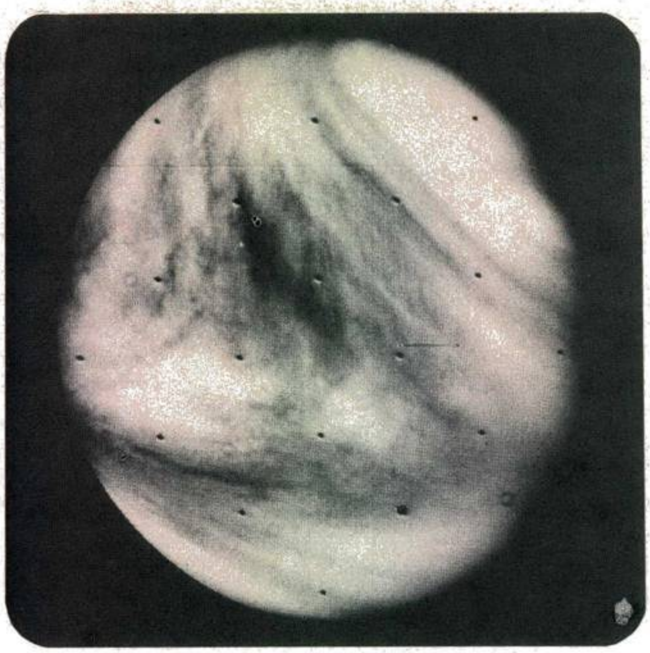
To increase the mass of the atmosphere, we might try to vaporize the native gases of the surface layers or the interior, or perhaps volatilize the icecaps and permafrost, or possibly import water and frozen gases from off-planet. Consider each of these possibilities, and choose the least impossible!

Perhaps the volcanos can indeed be set off again as Pournelle imagined, even if they do turn out to be ice volcanos instead of lava volcanos. Perhaps water ice and other frozen gases can be obtained from carbonaceous Deimos, the asteroid belt, or the rings of Saturn as in Isaac Asimov's **The Martian Way**. Brute force methods might indeed be the most cost effective for Mars.

Let's examine an ecological lever: the idea of melting the polar caps. We cannot safely stoke the fires of the sun, but we can imagine doing other useful things. We could increase the amount of sunlight hitting the polar regions; we could decrease the amount of sunlight blocked by the thin atmosphere; we could decrease the amount of sunlight reflected uselessly from the material we are trying to heat.

Nature may follow the first technique (increasing the amount of sunlight on the poles) in the natural precession of the Martian axis and in the orbital motion of the planet over the millennia. Altering planetary orbits, spin rates and axes might be a terraforming trick-of-the-trade in the 25th century, but it will be too much to expect of the first generation of planetary engineers in the next century.

Gathering solar energy and beaming it to the surface, terraformers begin the job of creating a Martian atmosphere. Operating on the principle of a microwave oven, power stations in space could selectively "cook" polar cap ices, melting ice and subliming carbon dioxide into the beginnings of a viable atmosphere. The climate changes that would occur on the planet dwarf the power input required to start the process of warming an entire world. Artwork by Dave Beck of The Garret Studio.



NASA photograph

Instead, tools which will soon be in operation in Earth orbit could prove useful on Mars and elsewhere. In the 1980s, space engineers will be building highly reflective (but very thin and light) metalfoil mirrors hundreds of meters on a side, which will circle Earth in geosynchronous orbits (keeping them over the same spot on the equator). From this vantage point, the first space mirrors (space planner Krafft Ehricke calls them *lunettas*) could provide nighttime illumination for rescue, emergencies or military operations. Larger mirrors (Ehricke's *solettas*), hundreds of kilometers on a side, could replace an entire state's street lighting — banishing night — at tremendous energy savings; they could also raise local temperatures several degrees, saving a frost threatened crop or perhaps steering a dangerous hurricane out to sea.

Now look at Mars. It receives about 60 percent as much solar energy as does Earth. As on Earth, the amount of sunlight at the poles is always reduced by the low angle of incidence of the sun's rays. To increase the polar energy flux by about 20 percent, we would need to use mirrors — not as large as 20 percent of the area of Mars, as considerably less would be sufficient.

No matter what their size, space mirrors will be capital investments which are not used up, and can be utilized elsewhere on other projects. The orbits of these space mirrors will impose constraints, since they cannot just hover weightlessly over the pole. Nevertheless, their orbits can be designed so that a number of mirrors can contribute to the concentration of sunlight on the icecaps.

There are other ways to terraform Mars. Reducing the opacity of the atmosphere ties in with keeping duststorms down, as it reduces the temperature extremes which lead to high winds, or reduces the amount of dust the high winds will raise. The latter could be accomplished by moistening the soil or by covering it with plant life. These techniques, too, are circular, because you cannot have one (more incoming heat and greater transparency, and therefore less dust to raise) without the other (water in the soil).

As our last alternative (or perhaps another factor to be used in combination with the two processes just outlined), the amount of sunlight absorbed by the polar caps could be increased. The whiter a surface is, the more heat it reflects and the less it absorbs. More than 3/4 the icecaps' sunlight is reflected. If that could be decreased by as little as five percent, the caps would begin to evaporate.

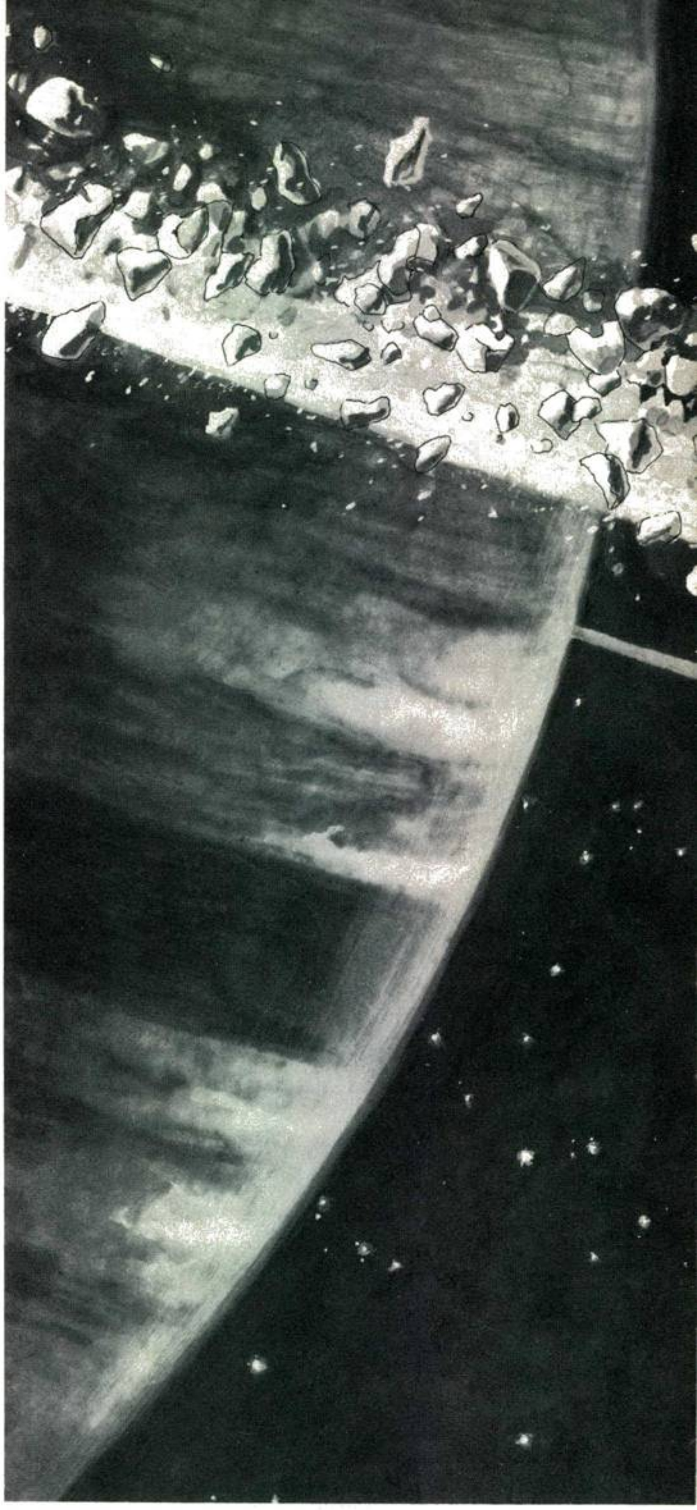
To darken the polar caps, perhaps planetary engineers could spread soot over them. Where could they obtain such material? Viking discovered that this is exactly what Deimos and Phobos are made of: very dark, sooty carbonaceous material. An electromagnetic cannon (mass driver) established on Deimos could shoot buckets of the brittle black powder down onto the polar caps. The material, rich in carbon, nitrogen, hydrogen and oxygen, would be a valuable fertilizer as well, once the caps were reduced.

If some stupendous engineering project manages to vaporize much of the Martian polar caps (at least the carbon dioxide parts; the water ice can follow later), the atmospheric pressure will temporarily be elevated. But what will happen when the destabilizing lever is removed? Will Mars freeze up again?

Many astronomers do not think so. Instead, Martian climate will have been switched from one stable state (today's) to another stable state (an atmosphere 10 to 100 times as thick, and warmer). Two processes can help maintain this change naturally — *advective heating* and the *greenhouse effect*.

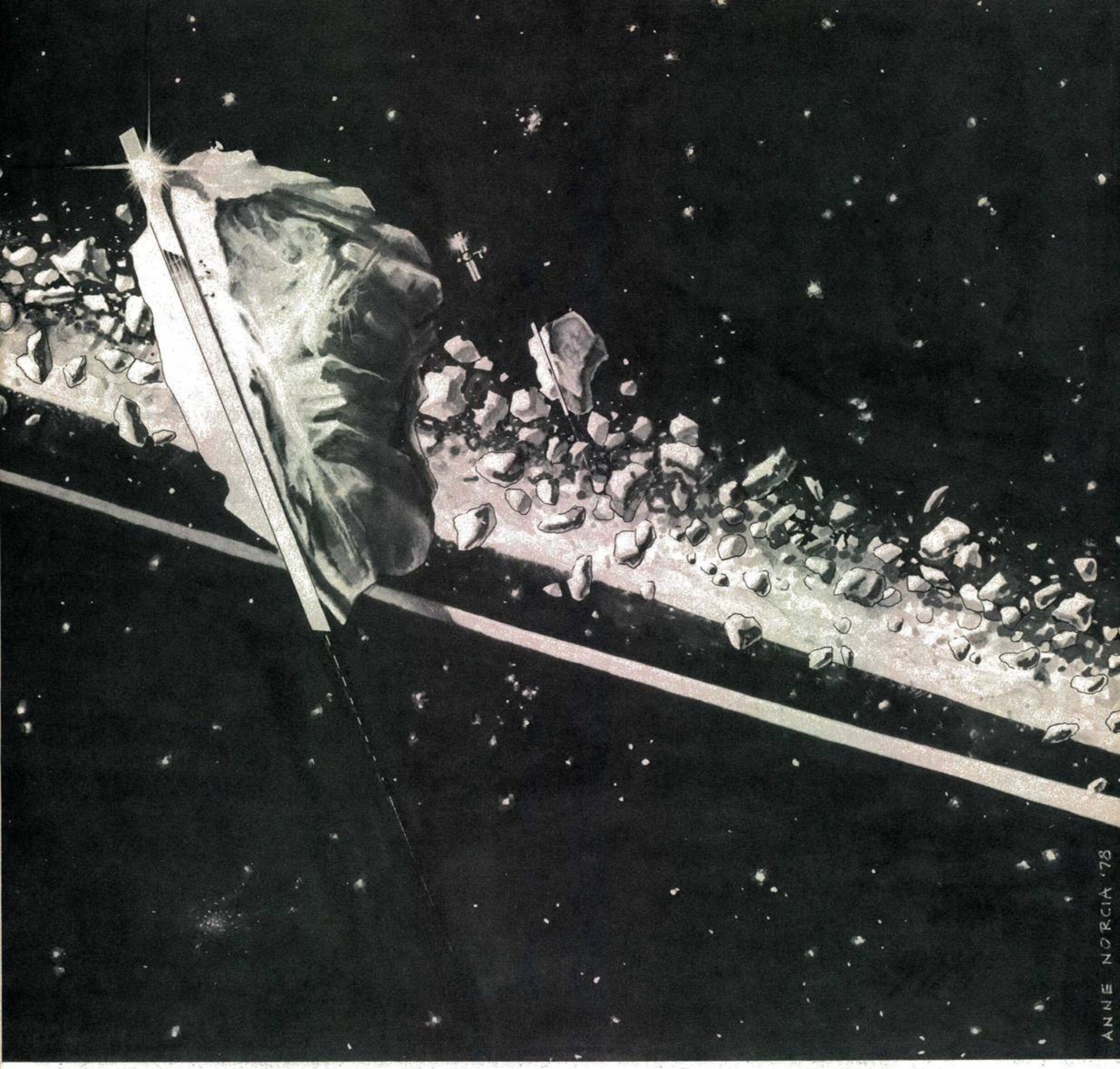
On Mars today, the sparse atmosphere is a minor factor in heat transport from the equatorial regions to the poles. The thin air does rush around, raising duststorms, but essentially all the heat which reaches the polar regions does so via direct sunlight. However, once the air is thicker, the atmosphere becomes a significant mechanism of heat transport known as advective heating. The warm southern winds can help prevent the northern polar regions (and, conversely, the northern winds help the southern polar regions) from ever getting as cold as they were before — even in winter when the sunlight fails altogether.

Therefore, the air does not freeze into dry ice in the winter, but stays gaseous. The poles maintain their warmth from the equatorial winds, too warm for the air to freeze out in the winter. Now we are on the happy side of a stable, circular, closed causal chain.



The second factor is the greenhouse effect. Without heating, on Earth in winter, gardeners' greenhouses stay warm. How? This physical process is extremely important for planetologists working on a wide variety of worlds.

Essentially, incoming visible light passes through an atmosphere and warms a planetary surface. Some of the energy is sent back toward space as heat in the form of infrared radiation. Certain components of the atmosphere, gases, aerosols and dust, may be transparent to the incoming visible wavelengths, but are not as transparent to the infrared wavelengths trying to go back through. So the radiation is absorbed in the atmosphere, warming it, or is reflected back into the ground, keeping it warm-

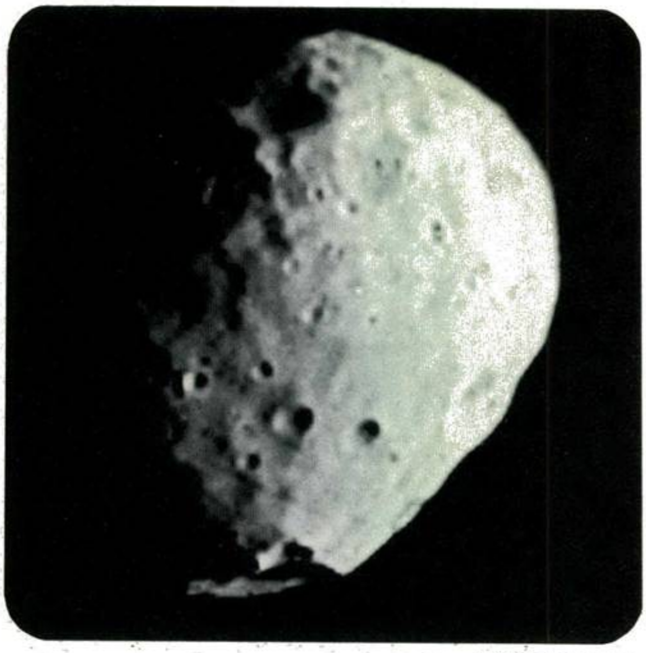


er too. The atmosphere seems to act like a blanket, although the physical process of the greenhouse effect is *not* the same as the insulating process of a blanket.

Earth has a greenhouse effect largely due to water vapor. Without it, Earth's surface temperature would be more than 70 degrees below what it is. Water vapor cools Earth, too. In the form of clouds, it increases the reflectiveness of the atmosphere, sending back much solar radiation before it can heat the ground. Both conflicting processes are at work simultaneously — a challenge to planetary scientists and meteorologists, and a compound problem for terraformers.

The composition of our hypothetical Martian atmosphere will be crucial to the successful exploitation of the greenhouse effect in order to further warm the planet. A hundred-fold increase of carbon dioxide alone (and Viking has shown that there is not enough carbon dioxide in the polar caps to accomplish this) would give a net greenhouse gain of only 15 degrees. If 1/10 of this new atmospheric pressure were due to water vapor, the greenhouse dividend would be more than twice as great.

Saturn's rings may be the most accessible source of water ice and frozen gases in the solar system. What needs will tempt humanity to dismantle one of the great natural wonders of the universe, we of the 20th century can hardly predict. But when water and frozen methane become another necessary resource, the rings will be waiting. The ring material is loosely bound by Saturn's gravity; collecting it and then accelerating it out of Saturn's orbit would pose no great problems. Artwork by Anne Norcia.



NASA photograph

So thick air leads to greenhouse-preserved warmth, which maintains the thick air, which in turn maintains the warmth. Once again we are on the happy side of a stable new situation, and we've done it with a lever: An orbiting mirror massing a few thousand tons has given Mars the gift of tons of air, and the sun contributed its energy free of charge!

The next step is oxygen generation. Here, original speculation centered on biological levers until Viking showed that adding water to Mars' soil caused it to give off free oxygen. That process needs more study, but it may be an example of a serendipitous discovery, making terraforming not as hard as previously thought.

Meanwhile, consider just the biological tools available. A few hundred pounds of algae sown on a fertile, warm, well-watered Martian landscape could multiply and spread across the planet in a matter of decades at most. While this was happening, the algae could convert much of the atmospheric carbon dioxide to oxygen, locking the carbon up into organic compounds in the soil.

Yet to be considered are implications of the availability of the "new form of life" discovered late in 1977 — a primitive type of cell whose metabolism seems almost too ideally suited for the biological processing of the atmospheres of alien worlds. Possibly the most primitive form of life on Earth, these bacteria might be readily modified where needed for use on Mars and elsewhere.

The NASA study on Martian ecosynthesis considered beginning the introduction of biological agents while Mars is still dry, cold and nearly airless. Scientists looked at the characteristics of certain simple plants which might be suitable for bioterraforming Mars: green algae, lichens, moss, and blue-green "algae" (actually a type of bacteria). According to the study, a combination of mats of blue-green algae and lichen might be able to survive today's Martian conditions, but they would grow very slowly and would be active making oxygen for only a few hours a day, even in the most benign season. With 1/4 the Martian surface covered with such biota, starting from present conditions, NASA computer simulations demonstrated that it could take more than 100,000 years to produce the minimum required for breathing. That does not account for the fact that even with sufficient oxygen, the remaining carbon dioxide would still be enough to suffocate a human being trying to breathe the new atmosphere.

In the brute force approach, once there is enough oxygen, you must also remove the excess carbon dioxide. But it requires a great deal of water. On Earth, water has aided the reaction of carbon dioxide with silicates to form carbonates (limestone). Venus, with its thick carbon dioxide atmosphere, and Earth, with very little, began with about the same amount. On Earth, it was converted to limestone, while an equivalent mass of carbon dioxide remains at large in Venus' atmosphere.

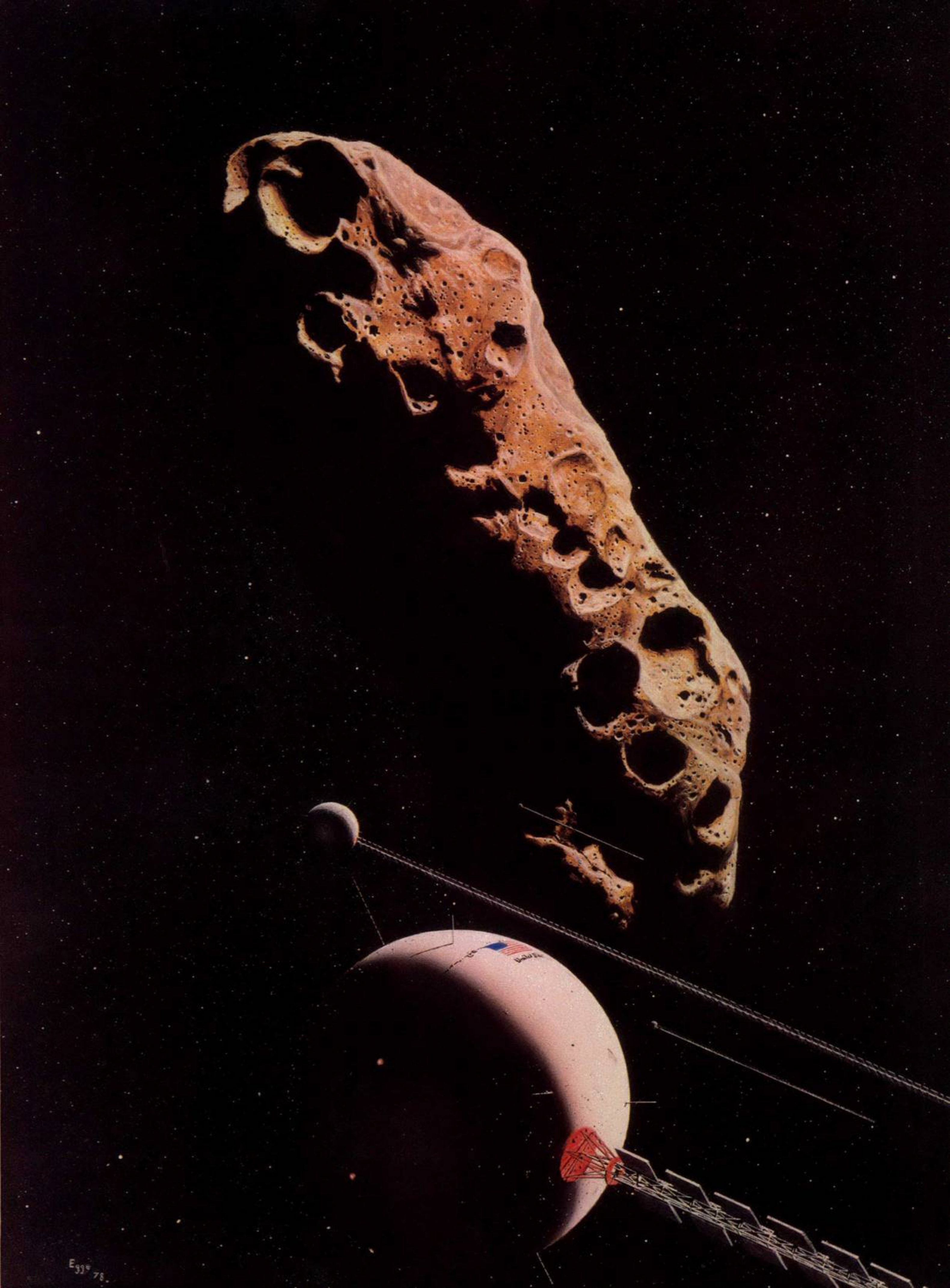
Oceans thus play an important role as atmospheric buffers, storing a significant amount of carbon dioxide dissolved in the form of bicarbonates. A large area of open water — perhaps 1/4 of a world's surface — is not simply an esthetic frill. Along with oceanic plankton and the humidifying effects of wind whipped sea foam, it is crucial to atmospheric engineering. So engineering of the Martian climate is imperative, in order to let the oxygenating plants grow on land and in the oceans. Even after this stage is reached, we still won't be done.

What should be sowed on Mars to maintain the atmosphere and create a food chain? The sterile alien desert, even temperate and well-watered, must be transformed into a garden of unearthly Earthliness.

Lichens and blue-green algae are a good bet, the NASA study concluded, even without genetic engineering to bring out their best points (and to suppress any taste they might have to consume oxygen). Lichens can grow on or in stone, excreting acids to dissolve a few hundredths inch of the rock's outer layers. They can even incorporate sand in their outer skin as an ultraviolet shield. Algae could grow below the surface of a layer of sand, where the ultraviolet level has dropped off but where visible light is still strong enough for photosynthesis. Later an ozone layer would form, blocking ultraviolet radiation before it reached the surface. But before that time, the biology would need to fend for itself.

The sands of Mars would become the soils and

Exploiting the asteroids has already been seriously proposed as a source of raw materials for building space colonies. Using a mass driver, asteroids could be moved piecemeal or wholesale toward Earth orbiting space colonies, where they would be refined for gases, metals, carbon and carbon bearing compounds, and glassy materials. Sunlight will provide the necessary limitless energy. This scene is set in the year 2030. Artwork by David Egge.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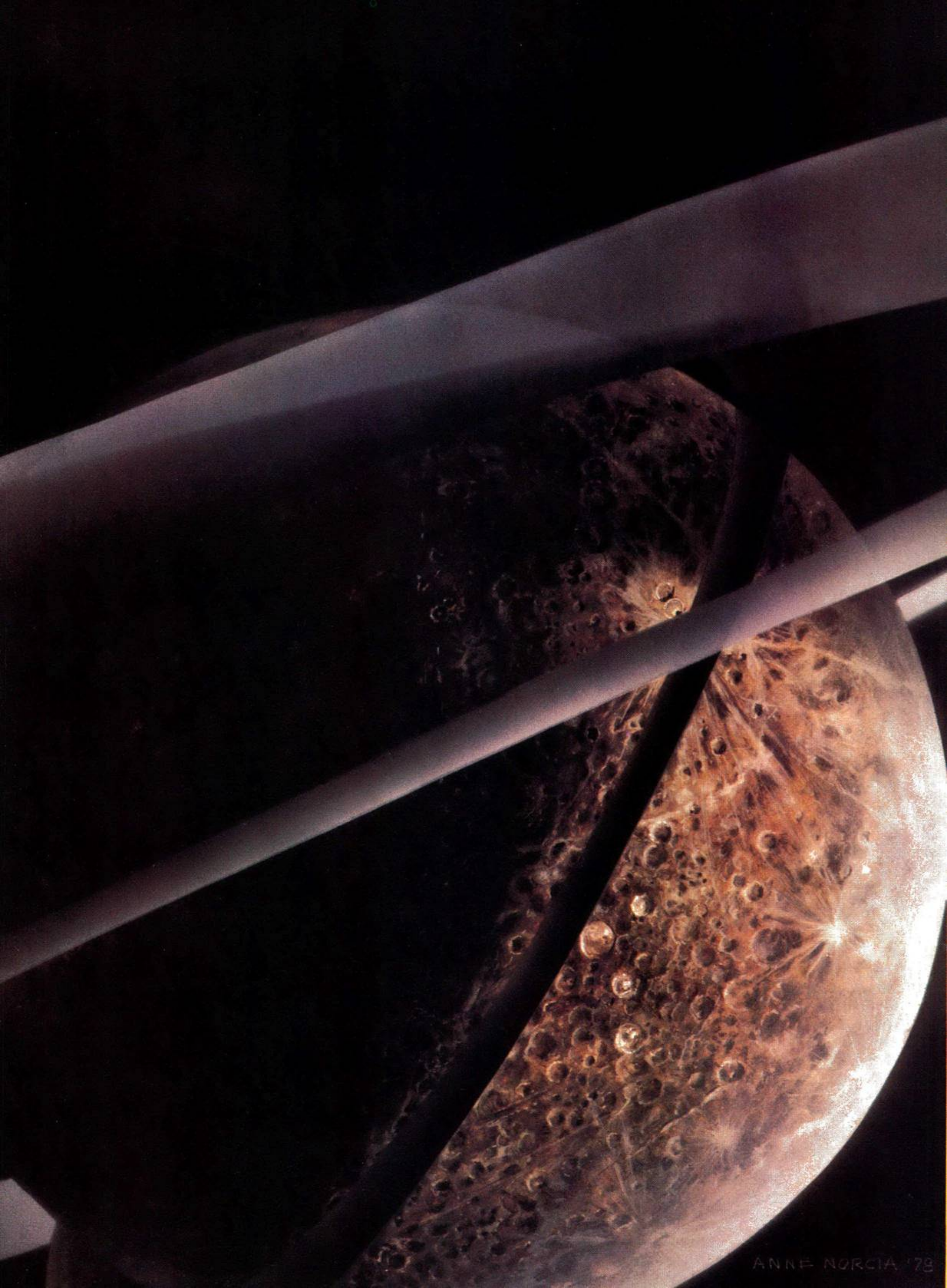
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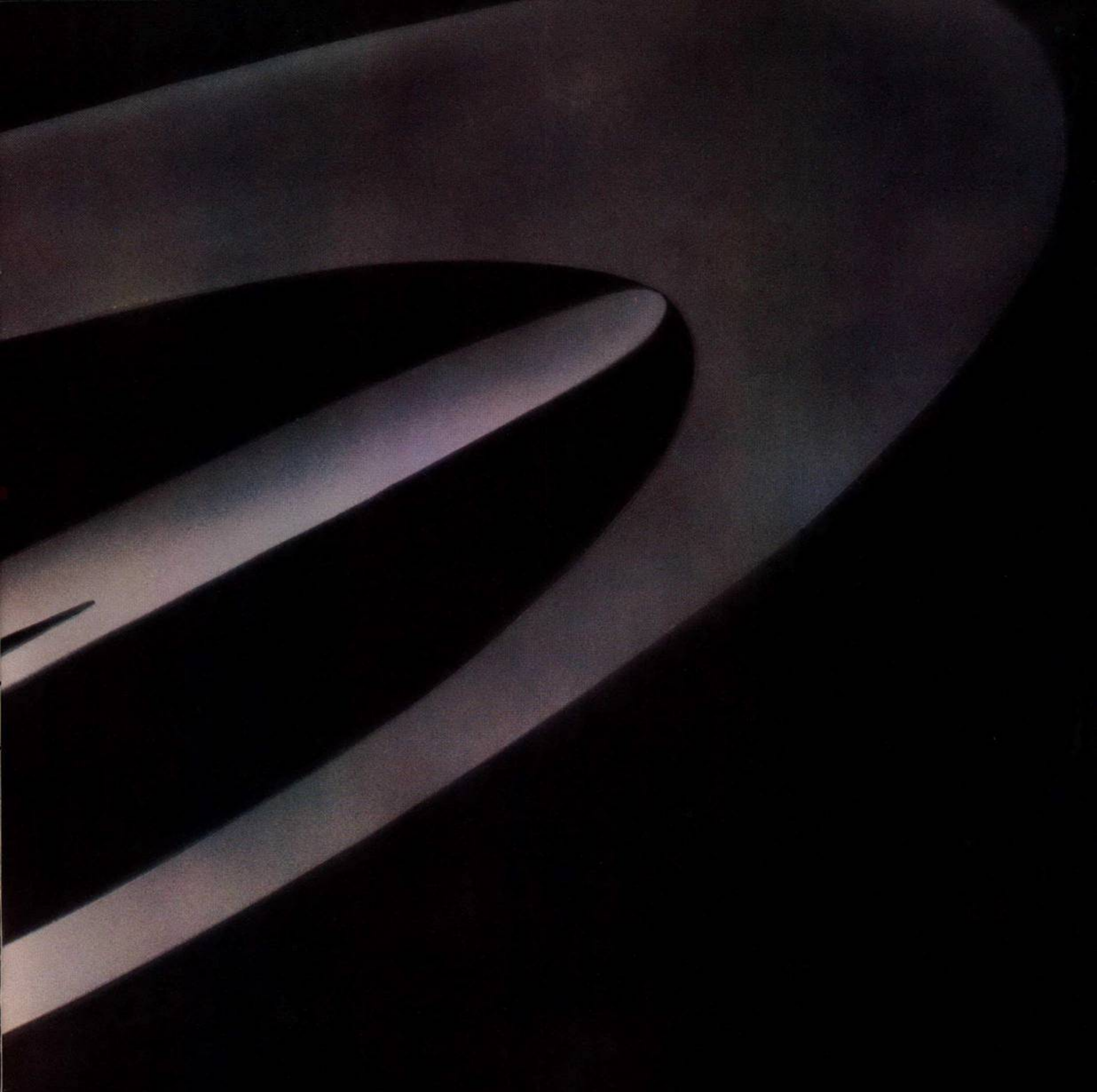
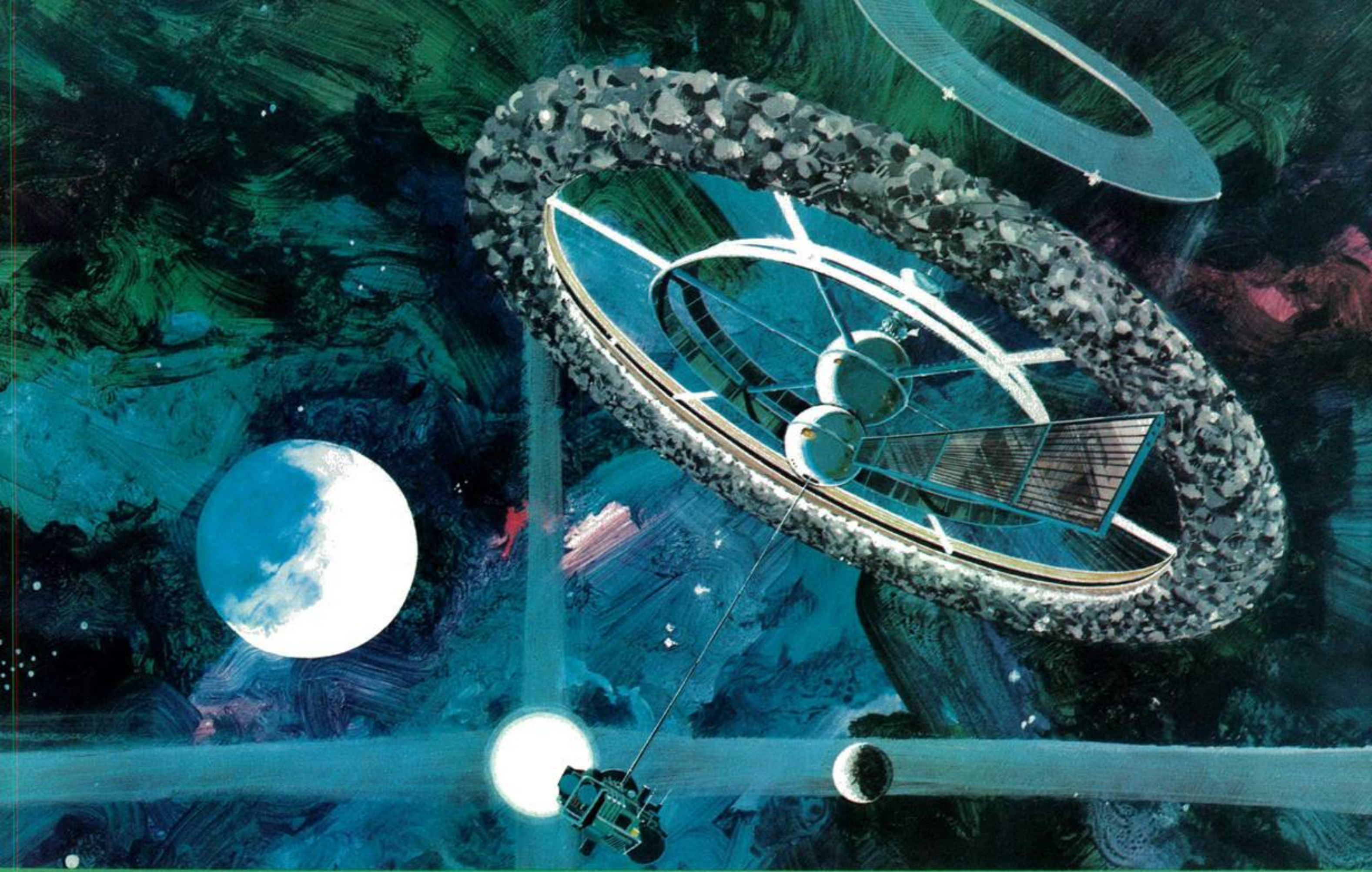


Before the surface of Mercury can be terraformed, the fierce reign of rock-baking solar radiation must be broken. While giant parasols and sunshades — beach umbrellas on a planetary scale — might work, a simpler scheme may be best. If asteroidal material is placed in an overlapping set of artificial rings, Mercury may be cooled at a very low technological cost. Like Saturn's rings, Mercury's sunshade would consist of billions of small orbiting chunks, but Mercury's rings would be a rocky debris rather than the ices of Saturn's rings. Artwork by Anne Norcia.



Living Without Planets

All these wonders assume that people will want to inhabit planetary surfaces, as they do today. A new direction has recently been pointed out, and it may short circuit the still unborn art and science of terraforming.

Several years ago, Princeton physicist Gerard K. O'Neill posed a seminar question to his students: Is a *planetary surface really* the best place to locate an expanding industrial civilization?

This is highly relevant here, since the resource called planetary surface area is not an unlimited one in the solar system. In fact, even if all the hard surfaces of the solar system were habitable, it would not amount to much more than several times as much surface area as is already available on Earth. It could not, even with the material taken from the cores of the giant planets, provide more than one order of magnitude increase in living space.

The key factor to consider is gravity. Besides keeping things in their places on shelves and streets, gravity seems necessary to organisms to provide a physical stress which helps maintain the strength and orientation needed to survive. Gravity also keeps air around.

Artificial space habitats, from Skylab to the giant space colonies of O'Neill's visions, can keep air around with walls, of course. Future space stations can provide physical stress by spinning. This is, by the way, strictly speaking *not* artificial or manmade gravity, but is only inertia masquerading as a kind of ersatz gravity. Someday science will be able to manipulate the fabric of the universe to create what can truly be labeled artificial gravity.

Advocates of these new ideas of space colonization enthusiastically point to the results of O'Neill's original question. The answer seems to be that deep space is the most ideal location for an expanding technological society — the only kind we have around, temporarily.

In free space, inhabitants can survive by encasing their air inside walls and generating ersatz spin gravity. It may be a hospitable and profitable environment, with the resources of weightlessness, high vacuum, high solar flux or absence of the same, and other features.

The breakthrough of genuine artifical gravity may come in 10 or 1,000 years. Subsequently, gravity generators will keep air on the surfaces, and no spins will be needed to fool mother nature into thinking it's in a real gravity field.

humus of a new world. The lichens could help break down the rocks. Algae could build up the soil and combine nitrogen into it. Organic matter could begin to accumulate, in compounds of carbon, nitrogen, sulfur, phosphorus, oxygen and hydrogen. This might still be the longest stage, taking up to a century or more.

NASA's study described the next step: "It would be most desirable to prevent such a one-way flow of elements into nonusable, high molecular weight organic compounds by establishing biogeochemical cycles which do not utilize free oxygen (to allow the oxygen to accumulate for breathing and ozone layer formation) . . . . While not minimizing the enormous complexity of designing a planetwide, efficient, steady state microbial ecology, this task does not seem to be insuperable."

Not insuperable, that is to say, for planetary engineers of the next century or two. Among the other tools of engineering, chemistry, geology and so forth, the tool of biology will be a paramount one.

So one day a human being may stand maskless under the blue Martian sky, and poke a hole into the ground to begin planting a field of pine tree seedlings. With a clean slate, mankind would open a new world.

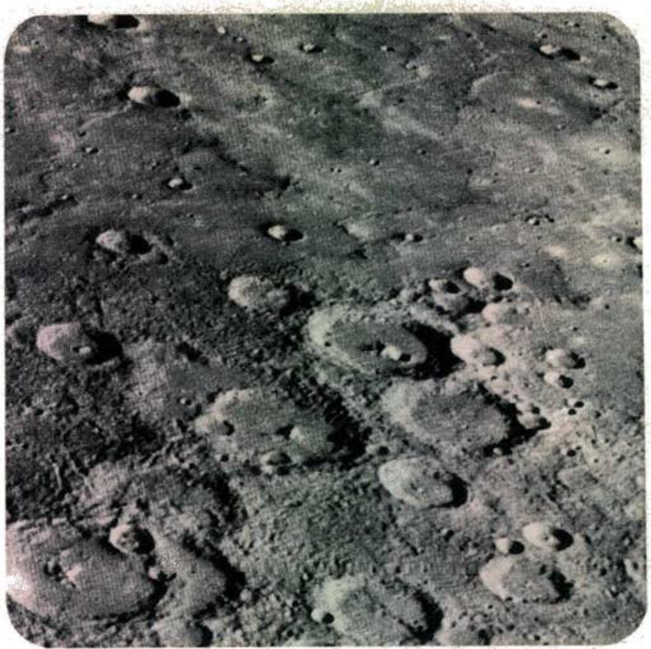
Creating a Twin Earth

The clouds of Venus are a tempting target for terraformers. More than a decade ago, Carl Sagan popularized the notion that humans might someday change the environments of other worlds. These clouds are a symbol of the lethal Venusian atmosphere, and underline the fact that the question of terraforming Venus depends on solving the meteorological problems first.

The air on Venus is heavier than the water of Earth's oceans. It consists of superheated carbon dioxide, at a pressure 100 times that of Earth's atmosphere, and is flavored with sulfuric acid stronger than that from an automobile battery. Its slow winds are more like ocean currents in their gentle inexorability and pressure.

The prospect of what would happen to an unprotected human being suddenly put out on the surface of Venus today is ghastly to imagine. No breath would enter the crushed chest. Against the enormous press of the ocean of carbon dioxide, the greater explosive force of boiling body fluids would shear off outer layers of flesh. The material would char and sear in the heat before floating off. Within minutes, all that would be left would be some calcium deposits and smears of soot atop the pitted native rocks.

Earth and Venus have about the same amount of carbon dioxide. On Earth, it's locked safely away in limestone, chemically removed through billions of years of limestone formation. If Venus is ever to be inhabited, its carbon dioxide atmosphere must be eliminated.



NASA photograph

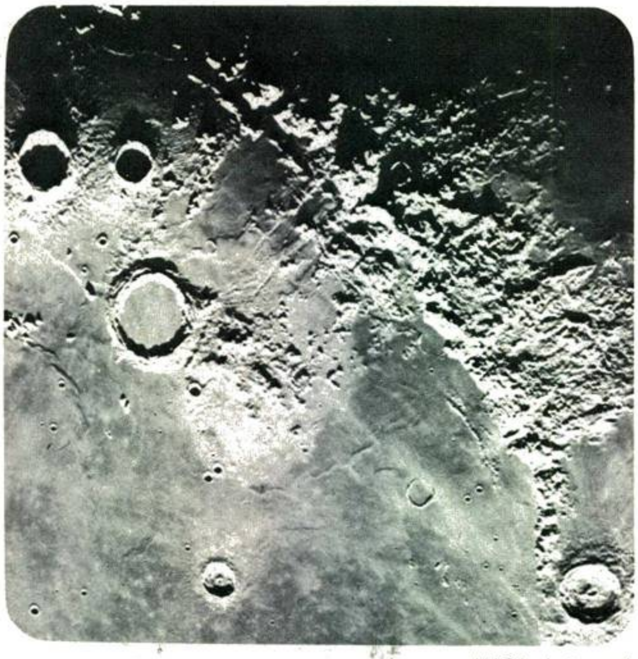
Perhaps someday human planet shapers will know how to snatch a world's atmosphere off into deep space and start again from scratch. But terraforming may not wait. The carbon dioxide ocean could be attacked chemically, geologically and biologically.

The intensive heat on Venus prevents any combination of the free carbon dioxide into the rocks; the free carbon dioxide maintains the heat via a greenhouse effect. Once again, we are faced with a stable closed causal chain which must be broken at one of its links.

That a strain of blue-green algae may be found or fabricated to thrive in the sulfuric acid clouds is not in doubt. The algae, as Sagan has suggested, would free oxygen while sifting elemental carbon down upon the scorched surface. Eventually the greenhouse effect could be broken, and surface temperatures would drop.

Venus needs water. If it ever had oceans, they are certainly gone now. Their hydrogen has diffused into space and the oxygen is locked away in the rocks. So, to moisten and cool the planet, terraformers may throw a "snowball" at it. With gentle acceleration, 10-mile-wide hunks of frozen water, ammonia, even methane could be steered from Saturn or beyond. The minimum energy fall toward the sun could take decades, so perhaps additional acceleration would be added. But hitting Venus at a range of a billion miles, even considering the perturbations from outgassing of the snowball, would not be difficult.

As the frozen mass approached the planet, it would build up an additional valuable resource above and beyond its substance: momentum. If aimed with foresight, the missile would come sweeping around the sun in a retrograde orbit and smash into Venus at a speed of more than 60 miles per second. It would not hit head on.



NASA photograph

Venus does not yet have the appropriate angular momentum for a new Earth. It spins too slowly for its iron core to generate a radiation shielding magnetic field. Hundreds of days of darkness between sunset and sunrise would thwart any attempt by photosynthetic Earth life to secure a foothold. So, Venus would be "spun up" on its axis, or a new axis more inclined to its orbital plane. The snowball from the outer solar system, if it contained enough water to cover the planet to an average depth of a yard, would also carry enough momentum to set Venus spinning with a 24 hour rotation. Water, plus an appropriate day/night cycle, would be two Venusian birds we could get with one cosmic stone — or cosmic snowball!

The next steps that would be used are unclear, although they would resemble the biological levers used to tame Mars. Venus would lose its hot, deadly atmosphere, though the process might take centuries. Hard engineering and hard thinking lie ahead, and the prize is an entire second planet Earth.

The Moon and Mercury

With Mars and Venus reshaped to sustain human settlements, planetary engineering would face harder challenges with sharpened skills, and a new generation of clever tricks and planetary levers. The next step would be to terraform our moon and Mercury.

The moon's atmosphere — or rather its lack of atmosphere — would be the first target. There has always been some gas around the moon, temporarily trapped from the solar wind or gently belched from the banked fires of the lunar interior. The air is so thin that molecules do not even bump into each other as they bounce around on the lunar surface. After spending a while on the moon, the atmospheric atoms and molecules are swept away by the solar wind, ionized and driven into the lunar soil, or heated to the point of escape velocity. Apollo missions doubled the mass of the lunar atmosphere with their rocket exhausts, but the foreign gases were lost within a few months.

However, beyond a certain point, some of the most important mechanisms for the dissipation of the lunar atmosphere are no longer effective. If the mass of the atmosphere were increased by a factor of about 10,000, the air would not escape very rapidly. It would still be barely discernible — but it would last a century or more.

An Earthlike atmosphere suddenly added to the moon would be fairly stable in terms of human timescales. Left to itself, a breatheable atmosphere would dissipate so slowly that it would take thousands of years to be reduced by half. Certainly whoever put it there in the first place could periodically replenish it.

But where would the atmosphere come from for a terraformed moon? We know that the moon is poor in volatiles, so the alternative may be to import from ice mines out past Saturn. On the other hand, perhaps sufficient gases could still be baked out of the lunar soil.

Ehricke has suggested using kiloton nuclear bombs placed underground. By blasting 100 foot chambers, each nuclear blast would free 10,000 tons of vital oxygen from the pulverized rubble. Ten such blasts would flip the moon's atmosphere into the long-term stable state. Several hundred more such explosions could generate significant air pressure.

Alternatively, moon orbiting parabolic mirrors could direct sunlight onto the lunar surface and bake the oxygen out continuously. The 10 blasts would be the energy equivalent of a 100-meter-square mirror focusing sunlight onto the moon for three years. Of course, that size is trivial; solar concentrators miles across could be built and used.

But the moon still lacks such volatile elements as carbon and nitrogen, as well as water. Interplanetary importation seems unavoidable. As with Venus, an incoming iceberg asteroid could use its momentum to start the moon spinning faster and at a predesigned spin axis.

With the moon fully equipped — a breatheable atmosphere and water in its maria — the biological tailoring would become another delicate task for ecological engineers. Your great grandchildren may yet play on the sandy shores of that great calm sea, Mare Tranquillitatis.

Though much like the moon, Mercury presents some additional unusual problems. The most notable, of course, is the intense solar radiation. Where Mars had to be warmed up, Mercury would have to be shaded.

Reducing the solar flux on a planet (it will be a while before the planet can be moved farther out from the sun!) could be accomplished at various levels. Some atmospheric features could be tailored, while other projects could occur a million miles out in space.

Perhaps, once an atmosphere and momentum have been imported, Mercury could be covered with highly reflective clouds. Perhaps, with a magnetic field operational, particles could be injected into the ionosphere, as science fiction writer Murray Leinster described some 30 years ago. But the best bet for keeping the sun off Mercury might be to use parasols — giant space umbrellas, in the most literal sense of the word.

Something could be built to block out most of the incoming sunlight. The shades could be installed between Mercury and the sun, or in orbit around Mercury. They could be solid structures, or clouds of dust.

Imagine a cloud of pebbles floating at the Lagrange point between Mercury and the sun. At 100,000 miles from Mercury, the cloud would have to be tens of thousands of miles across. Since the inner Lagrange point is unstable, new material would have to be introduced at regular intervals. Bringing an asteroid to the proper position and velocity could be tricky, as could be converting it into gravel without losing most of it.

Imagine another cloud made up of particles in orbit around Mercury, much like the rings of Saturn. Instead of just one ring, many separate deliveries of cosmic debris (the planetoid Icarus could be a source) could be made into different inclinations and altitudes, so that there would always be lots of shadow-casting debris over most of Mercury's surface. The landing pattern for an approaching spaceship would be tricky, to say the least! Once cooled, Mercury could be terraformed much as Earth's moon might be.

Artificial Planets

With the inner planets terraformed, there would be little rock left within easy reach. All the mass of the asteroid belt would not add up to a useful world. The outer planets and their satellites are mostly volatiles, which just won't do for Earthlike planets.

There are still more possibilities, although the crystal ball gets cloudy and imagination falters. In one direction, as suggested by futurist Freeman Dyson, Jupiter itself could be dismantled by increasing its spin rate. Its small rocky core would provide sufficient material for several more Earthlike planets, and its inner Galilean moons might be solid enough to be useful, once Jupiter's lethal radiation belts are turned off.

Another option would be to build a world from water. Imagine a 5,000 mile thick drop of water — a true ocean planet (as opposed to Earth, an ocean covered planet). Would the surface stay calm from the intense compression heat deep within it? What would be the dynamics of its spin, as the equator completed one revolution faster than the polar regions? How would people live on it, or in it?

Artificial islands built from artificially obtained pumice might serve the purpose as well. Giant floating city structures made from off-world metals might also be used. Ultimately, the world would be covered with descendants of South Pacific "floating trees", mats of vegetation which trail roots deep into the water and which have solid surfaces often acres in area. Exo-oceanographers would have a field day studying mineral balance and currents, and the ocean/air interface.

All the terraforming ideas we've discussed are predicated on the assumption that the only way to generate real gravity is to assemble a gigantic hunk of matter — a planet. If science and technology provide a better way, the very need for terraforming, and the need for planets at all, goes away. The popular image of giant space doughnuts and space cylinders may be workable for a few decades or centuries, but eventually they too will be as obsolete as Roman galleys and Spanish galleons.

What then? If people could live on small artiaficial worldlets in deep space, and if these habitats could be constructed by the thousands or millions, why would anyone want to engineer entire planets — especially when the rock of that planet could be spread out over a million times the surface area, on the artificial platforms? Will humans of the 30th century be dismantling all the planets of the solar system except for a few spectacular comets?

Terraforming may never become feasible or desirable. If the planets are left alone, they may forever remain uninhabited except by tourists, scientific expeditions and hermits. But the force of destiny, if such a concept exists, suggests that people move into every ecological and climatic niche which their technology makes available — whether it's hunters in the Arctic or nomads in the deserts. Even today the permanent residents of Antarctica and the ocean depths are preparing to move in.

So if it's at all feasible, some people will move to other planets. They may be a small fraction of the whole population, and they may not have the entire resources of the whole population, but they will want to go. If history is any teacher, the rest of mankind will be happy to see them go, too.

Tailored planets, artificial planetoids, the inhabited human influence stretching out toward the nearest stars — these concepts are exciting ones. They stretch the imagination and challenge our knowledge. Even if they never come to be, they will have been valuable exercises in man's learning to choose what's best for mankind. And if these ideas, or others now unimagined, ever do come to pass, they will make living on Earth a way of life as obsolete as living in trees.

James Oberg is currently helping to develop payload application software for Space Shuttle on-board computers at the NASA Space Center in Houston. He works as a computer specialist in nuclear/aerodynamic/laser stimulation and has taught courses in computer management. Oberg is a contributing editor to ASTRONOMY.

Venus Sparkles While Meteors Shower

May Satellites of Jupiter
9:00 p.m. EDT, 6:00 p.m. PDT

1	41023	• • ●••	16	42013	•• ●• •
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3	4103	• • ● •	18	40132	• ●• ••
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6	32140	• •••●	21	43012	•• ●••
7	30142	• ●•••	22	41302	• ••● •
8	1024	• ●• •	23	2013	• ●••
9	20134	• ●• • •	24	12043	•• ● • •
10	12034	••● • •	25	01234	●••••
11	01324	●••• •	26	1024	• ●• •
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The four major satellites of Jupiter orbit the planet in periods ranging from less than two days to 17 days. You can see them change position from one night to the next; their motions are often evident after only a few hours' observation. You only need a small telescope to detect all four, and you can frequently make out several in rigidly held (or tripod mounted) binoculars. This table shows the approximate positions of the moons at about 12 p.m. EST on the mornings indicated. The first column on the left shows the date; the second column identifies the moons by their positions relative to Jupiter's disk (1 =Io, 2 =Europa, 3 =Ganymede, 4 =Callisto, 0 =Jupiter's disk). The third column gives the satellites' positions as they appear through a telescope. The orientation of the satellite is given with south up as seen through a standard inverting telescope.

Now that the rages of winter are safely over, you may find it worthwhile to go out and do some observing for a few hours. The evening skies feature four planets conveniently placed in the western sky for viewing. With the added bonus of a meteor shower in the early part of the month which takes place during the new moon, you're almost assured of seeing something!

This month we've added a new feature to Sky Almanac: a box with upcoming events. If you've been frustrated by the slow delivery of your issue or are planning a vacation, this should be of some help. Each month we'll highlight the events of the upcoming month and include a planetary summary so you can keep track of what's happening with the planets.

Mercury

Mercury reaches greatest western elongation on May 9. The planet rises about an hour before the sun and should be visible about 11 degrees above the eastern horizon.

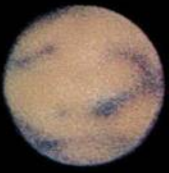
This is not one of the better times to observe Mercury. At greatest eastern elongation in March, the planet was located some 16 degrees above the western horizon in the evening sky. If you miss it this month, you can look forward to September when the planet will be at greatest western elongation, 16 degrees above the eastern horizon.

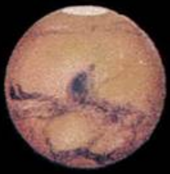
Venus

Venus is a planet that you can't pos-

At first glance you may not recognize the subject of this photograph as NGC-2237, better known as the Rosette nebula. This two hour exposure was taken on Fuji 100 film using a five inch f/5 refractor. Photograph by Paul Maley.

Planet Finder





Ⓒ Ceres

May	1	15
R.A.	19h40m	19h44m
Dec.	-24°20'	-25°03'
Mag.	+7.5	+7.4

Ⓐ **Mercury**

May	1
R.A.	1h03m
Dec.	+4°11'
Mag.	+1.1

Ⓑ **Mercury**

May	15
R.A.	1h49m
Dec.	+7°55'
Mag.	+0.4

Ⓜ **Mars**

May	1	15
R.A.	8h43m	9h09m
Dec.	+20°13'	+18°10'
Mag.	+1.0	+1.2

Ⓝ **Neptune**

May	15
R.A.	17h06m
Dec.	-21°22'
Mag.	+7.7

SUN

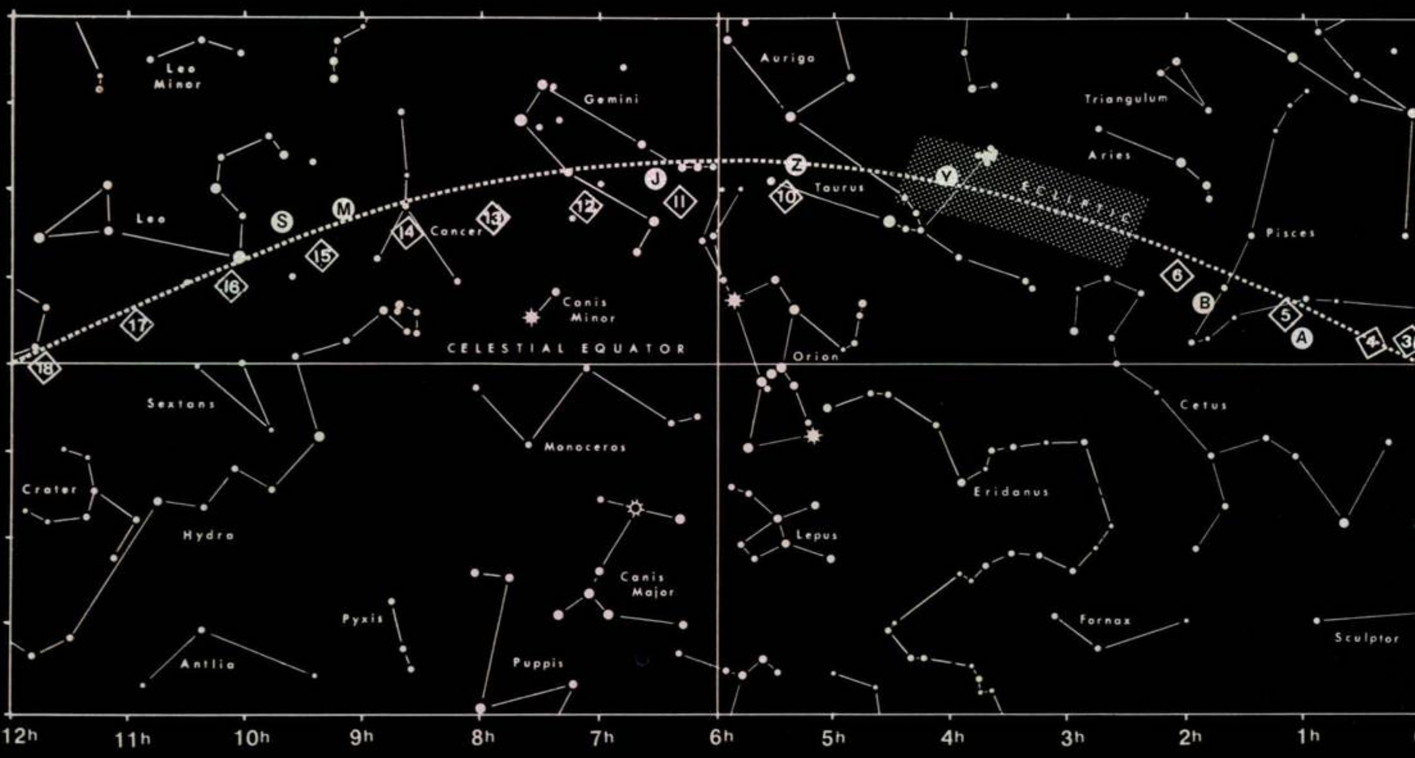
The sun is within the stippled zone throughout the month. Planets and stars near this area are not easily seen.

Ⓢ **Saturn**

May	1	15
R.A.	9h46m	9h47m
Dec.	+15°03'	+14°56'
Mag.	+0.6	+0.7

Ⓤ **Uranus**

May	15
R.A.	14h46m
Dec.	-15°39'
Mag.	+5.7

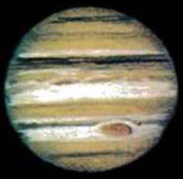

Leo Minor
Gemini
Auriga
Triangulum
Aries
Leo
Cancer
Taurus
ECLIPTIC
Pisces
Canis Minor
CELESTIAL EQUATOR
Orion
Sextans
Cetus
Monoceros
Crater
Eridanus
Hydra
Lepus
Canis Major
Pyxis
Fornax
Sculptor
Antlia
Puppis
S
M
J
Z
Y
B
A
3
4
5
6
10
11
12
13
14
15
16
17
18
12h
11h
10h
9h
8h
7h
6h
5h
4h
3h
2h
1h

The chart shows the positions of the moon, planets and brightest asteroids for the current month. Letters within the circles correspond to the letters beside each object in the data section above the map. Additional information about each object is given there. R.A. = right ascension and Dec . = declination, the two coordinates used to locate astronomical objects. The general coordinate system is indicated around the edge of the map. Mag . = magnitude, a

May 1978

Ⓥ Vesta

May	1	15
R.A.	17h17m	17h11m
Dec.	-15°08'	-15°13'
Mag.	+5.7	+5.6



Ⓙ Jupiter

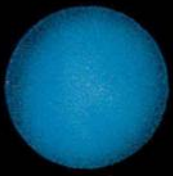
May	1	15
R.A.	6h13m	6h24m
Dec.	+23°26'	+23°22'
Mag.	-1.6	-1.5

Ⓨ Venus

May	1
R.A.	4h09m
Dec.	+21°39'
Mag.	-3.4

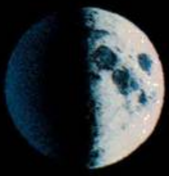
Ⓩ Venus

May	15
R.A.	5h22m
Dec.	+24°22'
Mag.	-3.4



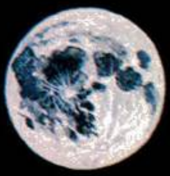
Ⓟ Pluto

May	15
R.A.	13h18m
Dec.	+10°40'
Mag.	+14



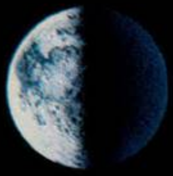
First Quarter

May 15



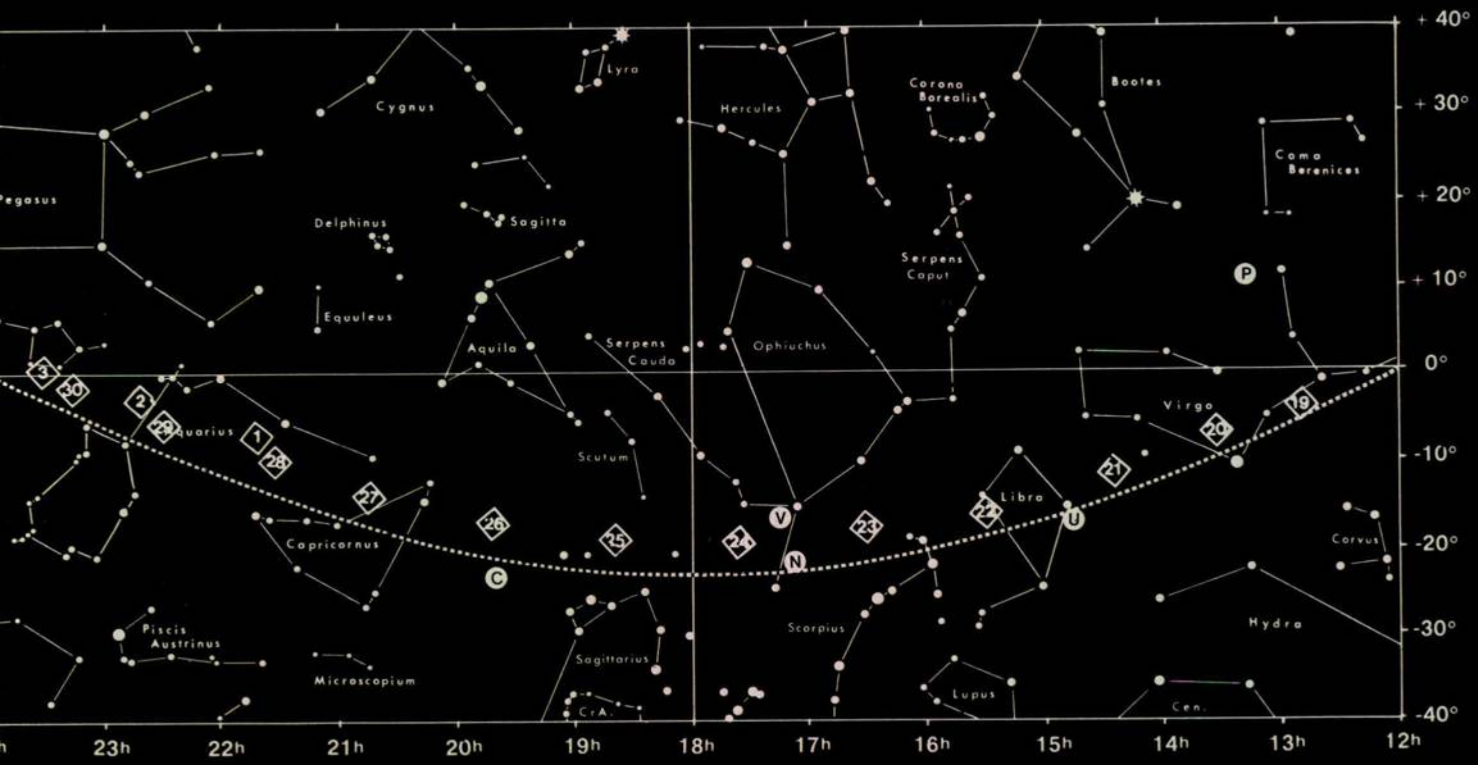
Full Moon

May 22



Last Quarter

May 28



+40°
+30°
+20°
+10°
0°
-10°
-20°
-30°
-40°
23h
22h
21h
20h
19h
18h
17h
16h
15h
14h
13h
12h
Pegasus
Cygnus
Lyra
Hercules
Corona Borealis
Bootes
Coma Berenices
Delphinus
Sagitta
Equuleus
Aquila
Serpens Cauda
Ophiuchus
Serpens Caput
Virgo
Aquarius
Scutum
Libra
Capricornus
Corvus
Piscis Austrinus
Microscopium
Sagittarius
CrA.
Scorpius
Lupus
Hydra
Cen.
P
V
N
U
C
3
30
2
29
1
28
27
26
25
24
23
22
21
20
19

measurement of the object's brightness. (The minus magnitudes indicate very bright planets.) The diamonds with numbers within them indicate the position of the moon for each day of the month: the numbers correspond to the dates. Positions of the planets are for the 15th of the month except for Mercury and Venus which are shown on both the 1st and 15th. Certain areas of this map and the Star Dome chart overlap each month.

sibly miss. The planet sets about two hours after sunset at the beginning of the month, and by month's end, about 2-1/2 hours after sunset. Twilight ends around 1-3/4 hours after sunset, so by the end of the month Venus shines in a relatively dark sky making it appear quite bright.

On the 9th, the crescent shaped moon (three days past new) passes six degrees south of Venus. Should the skies be cloudy that day, you can look forward to the 28th when Venus will pass close to Jupiter. The planet will be located a minimum of 1.6 degrees north of Jupiter, making a pretty impressive sight. It may be interesting to photograph the pair a few days before and after the 28th as they approach and pull away from one another. You'll need a camera, tripod and some fast (ASA 400) film. After you've set up your camera and tripod, open the aperture all the way (usually f/2 or f/2.8) and focus your lens until it reads infinity. Set your exposure time for 15 seconds and you're all set. Use your imagination in photographing the planetary pair; try framing them with some trees or perhaps some buildings. Experiment and see what you can come up with.

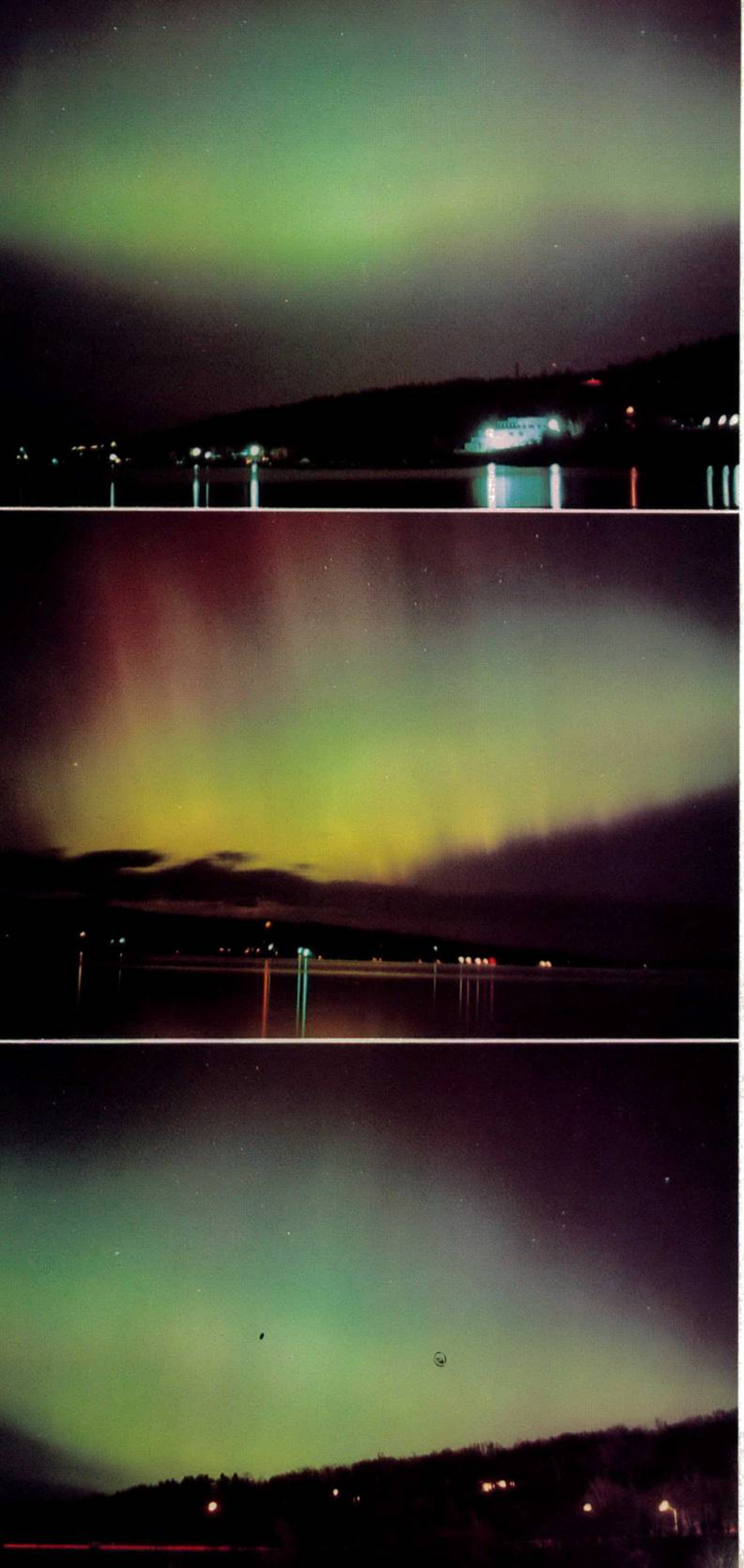
Mars

This month the red planet gradually moves eastward from the constellation Cancer into Leo. Around the 1st you can observe the planet situated a few degrees east of the Beehive cluster (M-44) in Cancer. Your best bet would be to locate Mars using the coordinates in our Planet Finder, or try eyeballing it if you're familiar with the planet's position. Then scan a few degrees westward until you find the Beehive (located at right ascension 8 hours 39 minutes and declination + 20 degrees).

On the 31st Mars will be closing in on the constellation Leo. Look for it a few degrees west of the bright star Regulus. On the 14th, the moon (then one day before first quarter) passes six degrees south of Mars. In the beginning of the month Mars sets shortly after 1 a.m. and by month's end sets at midnight.

Jupiter

Our solar system's largest planet is located in eastern Gemini this month.



The capricious veils and curtains of an auroral display on Dec. 2, 1977 are evident in this series of photographs taken from the south shore of Lake Cayuga in Ithaca, N.Y. The display began shortly after midnight, reaching a peak between 12:30 and 1:00 a.m., and ending around 1:30 a.m. (EST). The photographs were taken using a Miranda Sensorex II camera with a 50mm f/1.8 lens. The upper and middle shots were exposed for 25 seconds, while the lower shot was exposed for 30 seconds on Ektachrome 200 pushed to ASA 400. Photographs by Glenn Hardcastle.

On the 1st Jupiter is located west of an open cluster (M-35) about 15 minutes east right ascension and two degrees south in declination. The moon (between new and first quarter) will pass five degrees south of the planet on May 11. As previously mentioned, Venus will pass 1.6 degrees north of Jupiter on the 28th. In the beginning of the month Jupiter sets about four hours after sunset and by month's end, two hours after sunset.

Saturn

This ringed planet is located in the constellation Leo during May. It should be easy to find Saturn west of the backwards question mark or scythe that forms the head of Leo. Prominent in the constellation is the bluish star Regulus which markes the leading point of Leo's head.

On the 15th, the moon (at first quarter) passes five degrees south of Saturn. The planet was stationary on April 25 and has resumed direction motion among the stars. It sets around 1:30 a.m. on the 1st and at midnight by month's end.

Uranus

Our solar system's second ringed planet comes to opposition on the 5th. At this time Uranus (magnitude 5.7) is located 1.65 billion miles (2.64 billion kilometers) from Earth. In a medium sized telescope, you'll easily resolve its tiny greenish disk. The rings are far too faint to see, however, which is why they remained undiscovered until 1977.

Meteor Shower

The Eta Aquarid meteor shower reaches its peak on May 5. The shower, which averages 20 per hour, lasts for three days so you should be able to observe them from the 4th through the 6th. The meteors enter Earth's atmosphere extremely fast — 41 miles per second (66 kilometers per second) — making it the second fastest meteor shower according to the **Observer's Handbook 1978**. Only the Leonids, at 45 miles per second (72 kilometers per second), are faster.

Photographs

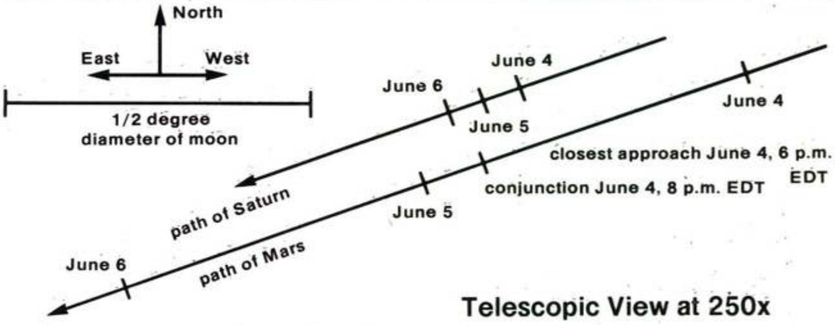
If you'd like to submit some of your astrophotographs to ASTRONOMY but aren't sure how to go about doing so, simply drop a note to Judy O'Dair, editorial secretary, and request a copy of our Guidelines for Submitting Photographs. We'll send you one by return mail.

A note to some of our more experienced astrophotographers: Good photos of some of the lesser-known Messier or NGC objects are always in short supply at ASTRONOMY. If you submit photographs of some of these objects, they'll be good candidates for publication in some of our more specialized observing articles.

Upcoming Events for June

4	Pallas at opposition Vesta at opposition Mars 0.1 degree south of Saturn
5	New Moon
7	Moon passes 5 degrees south of Jupiter Neptune at opposition
8	Moon passes 7 degrees south of Venus
11	Moon passes 5 degrees south of Saturn and 4 degrees south of Mars
12	Mars 0.8 degrees north of Regulus
13	First Quarter Moon
19	Moon passes 0.9 degrees south of Vesta, occultation
20	Full Moon
27	Last Quarter Moon
29	Mercury 5 degrees south of Pollux

By the end of the month Mercury will be visible in the west, setting 1 hour 15 minutes after sunset. Venus continues its dominance of the evening skies, setting about 2-1/2 hours after sunset. Mars is gradually moving westward; in May it moves from Cancer into Leo and sets about 5-1/2 hours after sunset. In June, Mars is still in Leo and is visible for most of the evening, setting around midnight. In May Jupiter sets three hours after sunset and in June sets 1-1/2 hours after sunset. After June the next time you'll see Jupiter will be in the morning skies of August. For the months of May and June Saturn is pretty well situated for observing in the evening hours. With a small telescope you should easily be able to observe its famous ring system. At the end of May the planet sets around midnight; by the end of June it sets around 10 p.m., 2-1/2 hours after sunset.

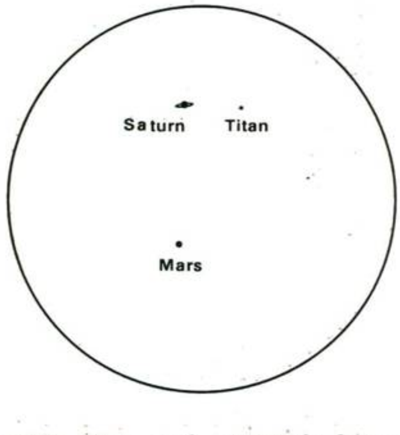


Mars, Saturn in Conjunction

On the night of the 4th an attractive pairing of planets takes place when Mars passes 1/10 degree south of Saturn. You won't have to get up at an ungodly hour to see it either — the planetary pair will be visible high in the southwest at sunset and set about four hours later at midnight. Mars is moving quite rapidly so the timing involved in this planetary conjunction is very important. The moment of minimal separation, 1/10 degree, occurs around 8 p.m. EDT (5 p.m. PDT), so you should set up your observing equipment just after sunset. Closest approach occurs before sunset on the west coast, so by the time the pair sets around midnight, Mars is already pulling away from Saturn. Mars (magnitude 1.5) and Saturn (magnitude 0.8) are situated in the constellation Leo, seven degrees east of Regulus and two degrees north of Rho Leonis. To unaided eyes, this grouping will be quite a sight.

With a small telescope you'll see both planets together even in a 100 power field. A pair of binoculars (if you have them) will aid observation by making the color contrast between ruddy Mars and yellowish Saturn more striking. Hopefully, if the weather cooperates, you can observe the pair a few days before and after the event as they approach and pull away from one another. Two days before the conjunction, Mars is seven degrees west of Saturn (on the 2nd); it is 1/2 degree west on the 3rd. On the two days after conjunction, Mars is 1/2 degree southwest of Saturn (the 5th) and seven degrees southwest on the 6th. See for yourself how, over a period of a few days, the red planet outdistances the ringed planet.

Telescopic View at 250x



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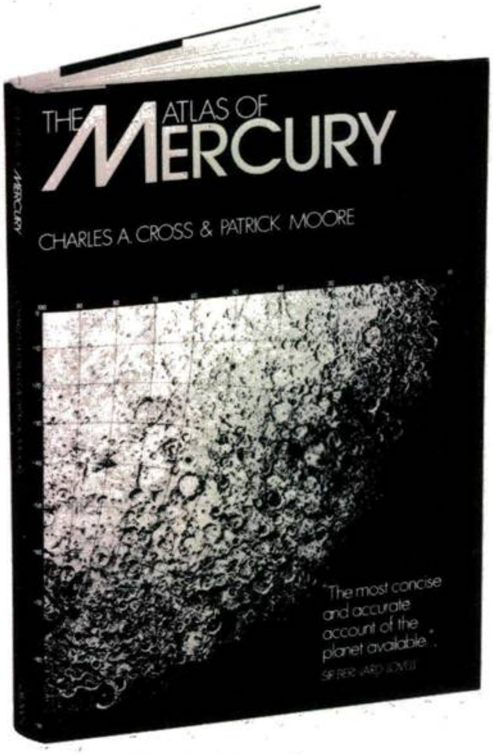
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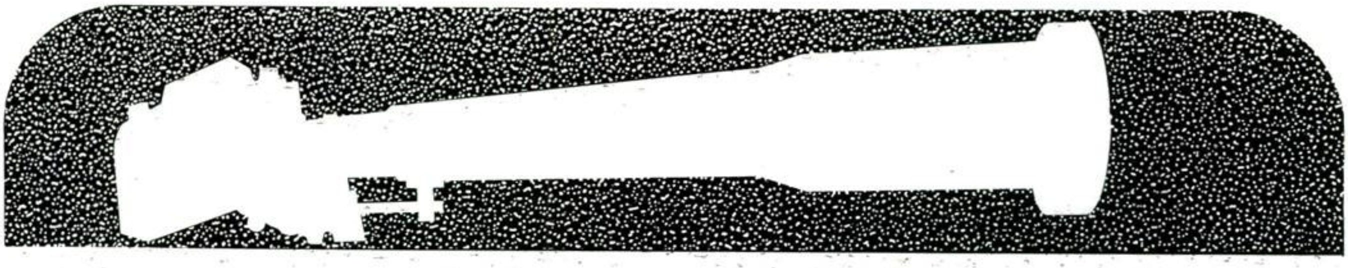


PHOTOGRAPHY IN ASTRONOMY

Blink for a Nova!

by
Ben Mayer

If you find "just looking" through a telescope doesn't satisfy you or if you have that itch to "do something useful", you may find a photographic search for novae just the thing for you. As many as 20 to 30 novae of magnitude eight or brighter appear each year. Few of them are discovered. Nova Scuti was at magnitude seven in 1975 for over a month before anyone discovered it! Regular *blinking* of the whole sky could change matters for the better.

A PROBLICOM Survey

To coordinate the efforts of all who wish to participate in an organized program, the PROBLICOM Survey has been organized. Plans are to cover the entire celestial sphere photographically, with each participant shooting one or more assigned targets every month and blinking the resulting photos on a regular basis. To avoid duplication and achieve maximum coverage, participants in the survey will receive four sets of celestial coordinates six hours apart in right ascension with varying declinations. Everyone will be afforded yearround opportunities for meaningful work and potential discovery.

The survey is particularly suited for club participation. Since one PROBLICOM projection device can serve an entire group, members can bring their pairs of slides to monthly meetings using a club owned (or built) system to blink their slides with everyone sharing in the exciting research.

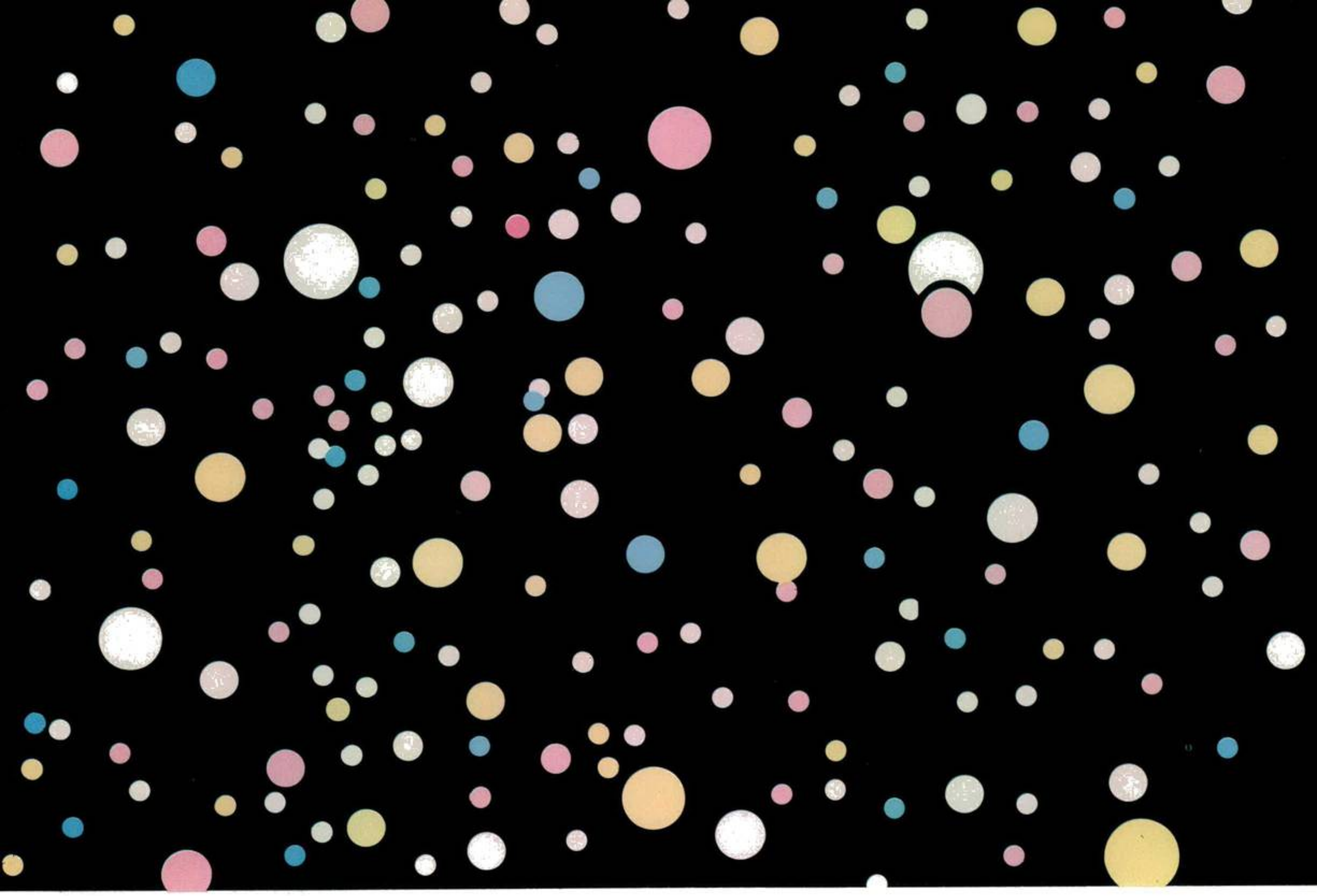
The ability to align your camera mounting with the north celestial pole, familiarity with setting circles, and ownership of a home built blinking device are the only requirements for participation in the survey.

Join a group of dedicated blinkers; it will put you on the threshhold of discovery! Send a self-addressed stamped envelope to Ben Mayer, 1940 Cotner Ave., Los Angeles, Calif. 90025.

And just what is *blinking*? Well, the full name is *pro*jection *bli*nk *com*parison (PROBLICOMing for short). It's a method — using simple equipment — for finding things that change in the sky. Not only does projection blink comparison permit you to start on a realistic journey to discovery, it also allows you to see planetary motions or watch brightness changes in variable stars.

You don't need vast knowledge of the heavens with all its constellations, nor costly sophisticated equipment. The method was developed for those who know only very few constellations or even stars. It's designed for stargazers who wouldn't notice a bright new star even if it appeared in the Big Dipper, let alone a faint one in Monoceros — wherever that may be! All the equipment that's needed is:

1) any 35mm camera with a standard 50 or 50mm lens or, ideally, a 135mm telephoto lens;
2) two slide projectors of the same make (if you only own one, you might share a friend's matching one and make your discovery program a joint effort);
3) a small 120 r.p.m. "synchron" motor, available from most electrical supply houses, and
4) a home built gadget to hold two projectors (similar to that shown on page 36).

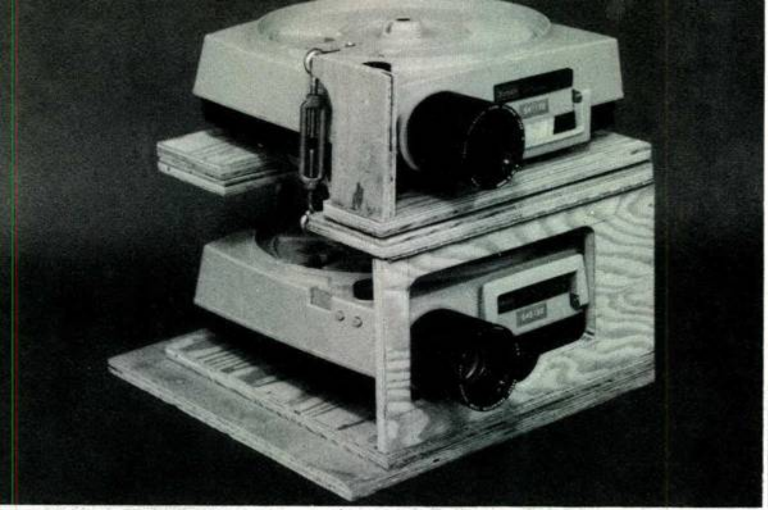


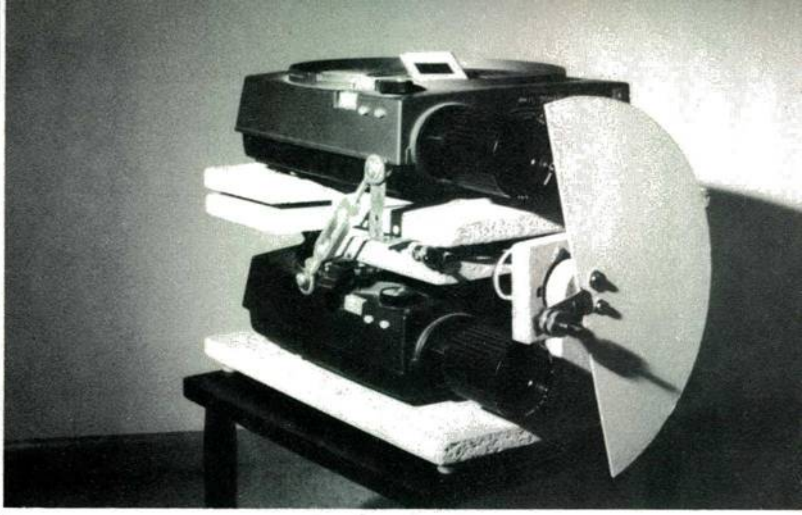
Above and on page 37 is a simulation of blink detection of novae, asteroids and variable stars. If you look at both page 37 and this page, you'll see two star fields that seem identical — but look a bit closer. Try flipping rapidly back and forth. The simulated nova will flash on and off, the asteroid will hop back and forth, and the variable star will shrink and swell in synchrony with your flipping. With a real PROBLICOM search, you'd be looking for the real thing!

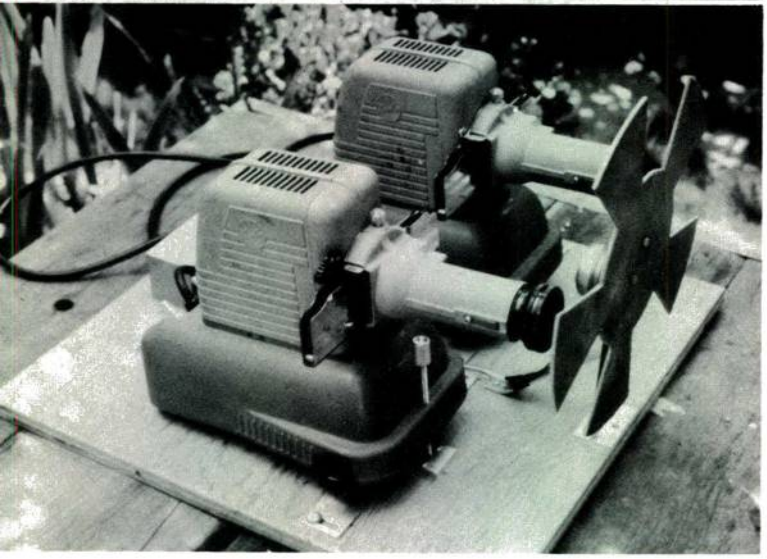
Taking star photographs with a 35mm camera isn't difficult. simply load your camera with some High Speed Ektachrome ASA 200 film, put it on a tripod, aim it by centering some bright star which you know in your viewfinder and, with your lens wide open, expose for two minutes. True, there will be a little trailing of the stars, but you'll get a meaningful record. If you piggyback your camera on your telescope and turn on the motor drive after aligning your equipment with the north celestial pole, a five minute exposure will yield more stars than the naked eye can see. Unlike the human eye, film "collects" starlight — just like a dish left out overnight in a drizzle would collect water and be full by morning.

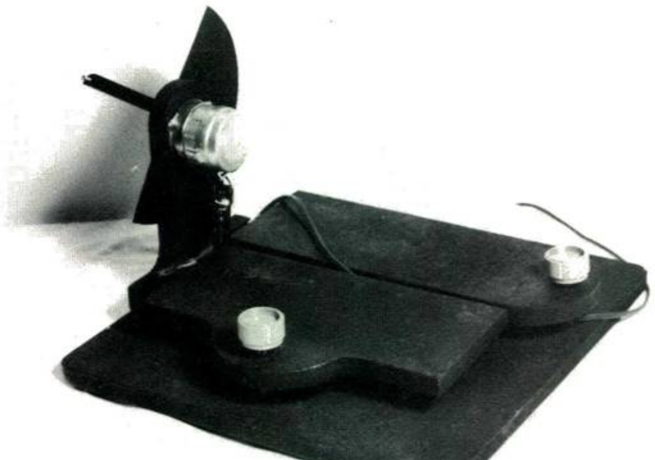
You'll have a record of the stars surrounding the target star of your choice: In scientific parlance, this is your *reference slide.* Write the date on it, the exposure time, the name of the target star and its coordinates (if you're familiar with those), and file it away. If you shoot the same target star again next month (again centering it in your viewfinder and exposing as before), you'll have taken your *data slide.* If you casually compare the two photographs by projecting them onto a screen, they'll look virtually identical. Depending on the area you choose, they'll show hundreds or even thousands of stars all seeming to be in the same places in both photos. But are they? Has anything moved? Has a new star made an appearance — a faint nova perhaps, or an asteroid? Could there possibly be a tiny comet in last Sunday's picture — a tiny fuzziness that wasn't in last month's slide? While projecting, it's impossible for you to detect any change unless you keep taking out one slide, putting in the other, checking a small area and then switching slides again. It's tedious, to say the least, and since the stars are sometimes so close together and look so much alike, you'll go out of your mind before you've even worked your way across the top edge of the two slides.

But there's a simpler way which professional astronomers employing costly machines have used for years: It's called blinking. So-called *blink comparators* (which cost thousands of dollars) are standard equipment in astronomy departments at many universities, and aid professionals in their discovery work. The pictures taken for comparison are viewed through microscope eyepieces while you sit at a bench-like machine. Instead of switching the pictures back and forth as we just tried to do with the slides, both photographs are presented to the eye one after the









Top left: A PROBLICOM simply includes two projectors, a rotating shutter (removed for clarity in this picture) and a frame that allows you to adjust the two projector images into precise coincidence. Photograph and PROBLICOM by Walter Hamler. Top right: The rotating shutter covers first one projector lens, and then the other. Photograph and PROBLICOM by Philip Dombrowski. Bottom left: Any method of aligning the projectors is satisfactory. Note the height adjusting screw at the front of one projector. The other projector can be adjusted from side to side. A five bladed shutter was used with a 30 r.p.m. motor for blinking. Photograph and PROBLICOM by Ray Coutchie. Bottom right: Shown without its projectors, this simple PROBLICOM base permits both horizontal and lateral adjustments. Photograph and PROBLICOM by Bruce Grim and Patrick Wiggins.

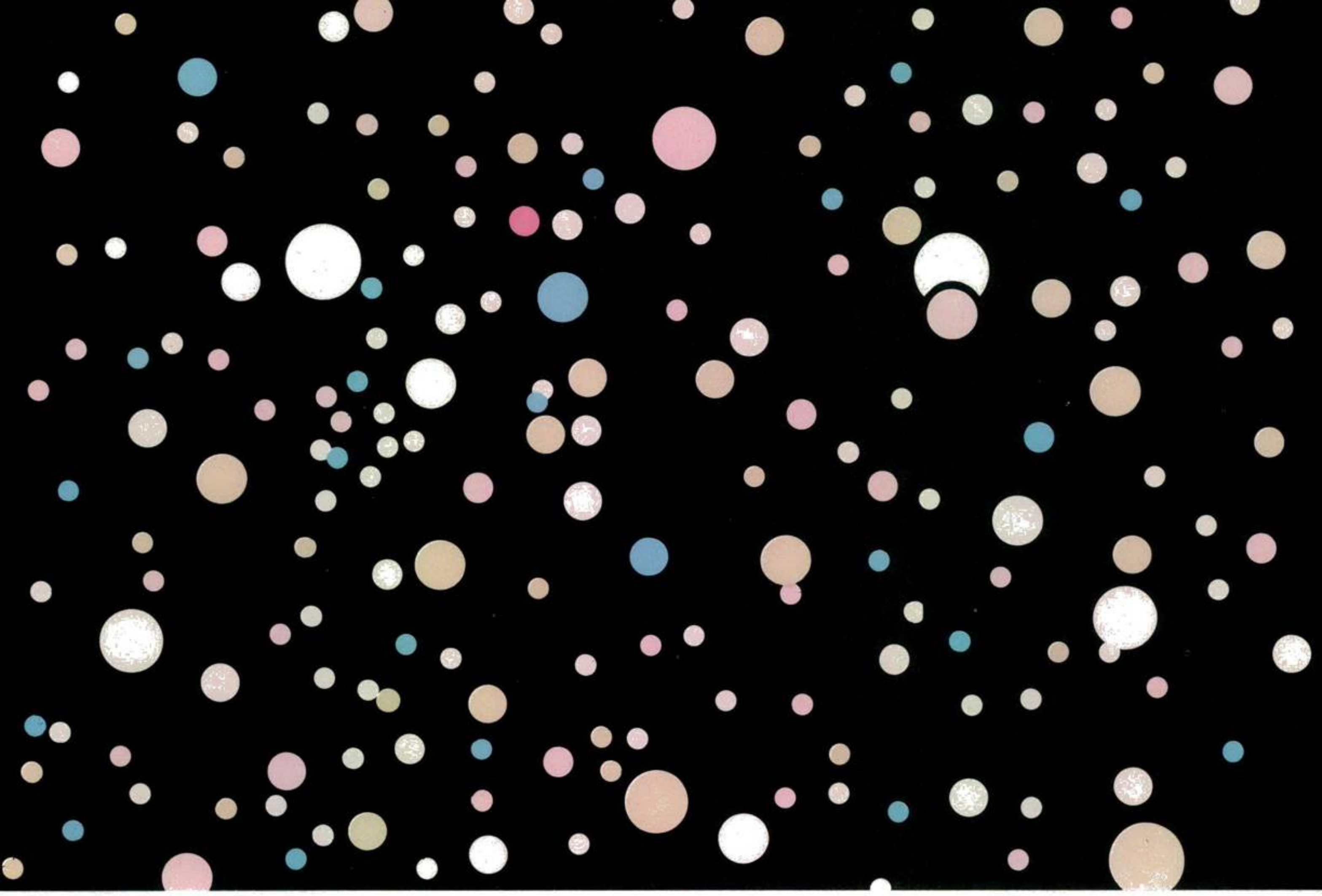
other in rapid succession so that they appear as one picture. This is done by inserting the pair of photographs into the comparator in such a way that all stars overlap each other. The rapid change from one picture to the other is achieved by turning the lamps behind the two pictures on and off alternately.

If there's an object in one of the two photos that wasn't in the other, it'll immediately attract attention to itself by blinking on and off at the same rate at which the lamps blink, while all the other stars which appear in identical places in both pictures stay still because they overlap.

This elegantly simple principle can easily be adapted to your slide projection method. All that you have to do is load the two different slides into *separate* projectors, and then project the images onto a screen in such a fashion that they overlap as precisely as possible. Since it isn't simple to build an electric device to switch the projector lamps on and off in rapid succession, just try blocking the light beam first of one projector and then the other, and back again. If you use a 120 r.p.m. motor, you'll get to see 60 separate glimpses of the newer picture per minute and 60 separate glimpses of the older photo. They'll come very fast and alternately. To the eye everything will look like one projected image except for the things that have changed: Something new, different, brighter or fainter, or objects which have moved. These will immediately draw your attention by blinking on and off or by jumping back and forth.

You can test this method by making a photograph of a star field containing a planet or an asteroid, and then making another a few weeks later. In the case of an asteroid, you only need to know its general location. If you try a planet, don't center it in your photograph, but shoot the same star field on both occasions.

To demonstrate the principle, put two projectors of the same make with similar lenses side by side and insert the two slides in them. Aim both images onto the same screen so that the two projected star fields overlap. On your first try you'll probably have to spend a little extra time to achieve the good register necessary for effective blinking. When the two pictures appear very nearly as one, cut off the light



Now that you've found the nova, the asteroid and the variable star (we hope), imagine searching this same imaginary sky without blinking — remembering that this picture shows about one percent as many stars as a good search photo might! Blinking has long been used by professional astronomers to look for variable stars and asteroids — and the planet Pluto was found by blinking! Today, however, there is no regular professional search for novae. That search is yours.

beam of one projector and then the other with your hands. Look at the screen while you're going back and forth at a fairly rapid pace between the two beams, and you'll find the asteroid or planet jumping back and forth! If you photograph exactly the same star fields a few months later, and blink it against a photo still showing the planet, you can simulate the "disappearance" of an object — the exact opposite of a discovery.

Color film shows stars in beautiful colors, realistically portrayed on a deep blue-black night sky background. This makes blinking a pleasant and easy pastime. With less expensive black and white films, you can use the negatives for projection by cutting the film and inserting individual frames into cardboard holders. If you use both color and black and white, you'll be able to check anything you might find in one of the two photos taken on the same night, one after the other.

Avoid False Alarms!

Since you're bound to discover all kinds of moving objects in the sky, establish contact soon with a knowledgeable person at the nearest college, observatory or planetarium. Report on what you are doing and ask whether you have permission to call at odd hours to check your findings. This will avoid false alarms. It's also a good idea to shoot two pictures of the same target area in succession in order to rule out minute film damage which can look deceptively like a star, comet or nova.

As you build your own collection of *data record* photos, you'll want to blink not only your newest shots against last month's but against your older and oldest records. Thus you'll be able to see variable stars going through their periodic cycles sometimes from complete invisibility to maximum brightness and back again.

You can blink on your own, or you can blink with the PROBLICOM Survey group, but either way, you'll have the satisfaction of knowing that if you find a nova, some of the biggest telescopes in the world will be pointing at it the very next night — and if you hadn't found it, it might have gone undiscovered! It's a marvel that such simple equipment used in a regular program is all that's needed to maintain a lookout for distant explosions of stars or a possible comet.

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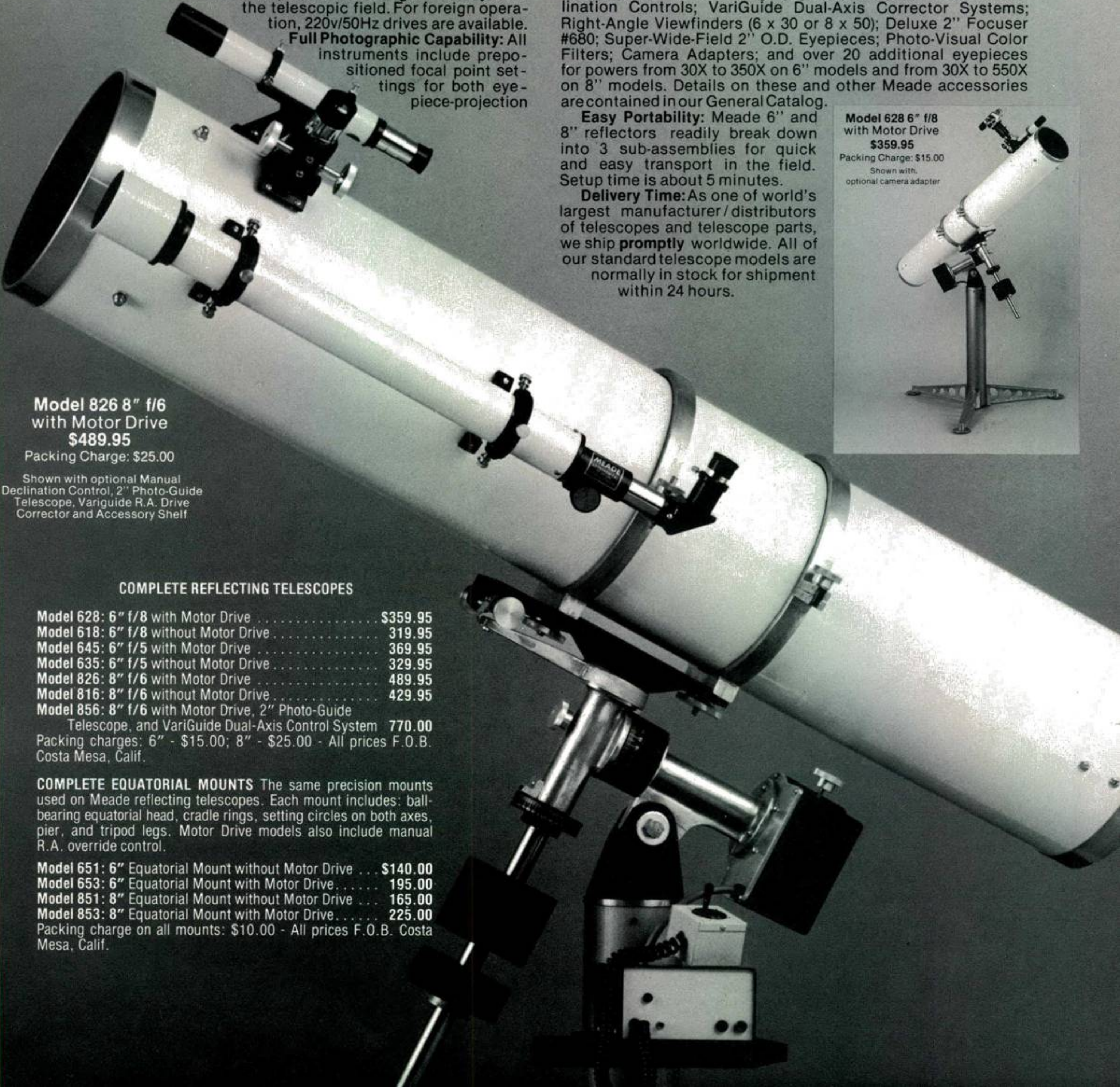

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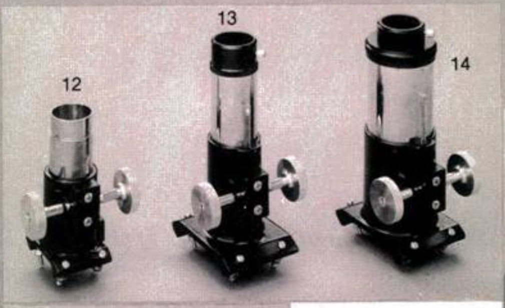

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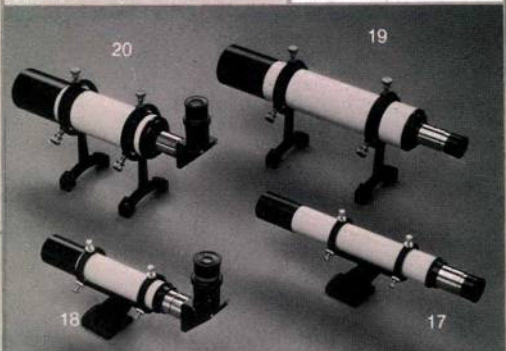

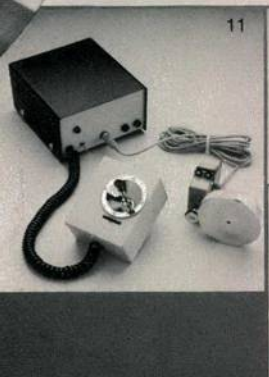

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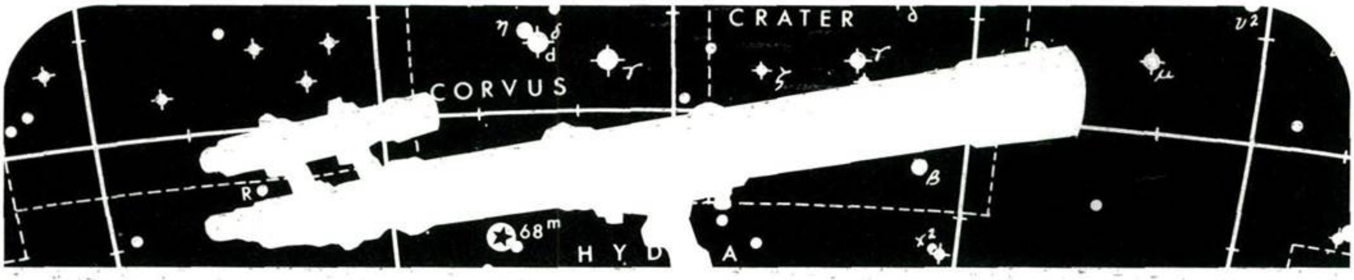


Celestial Software

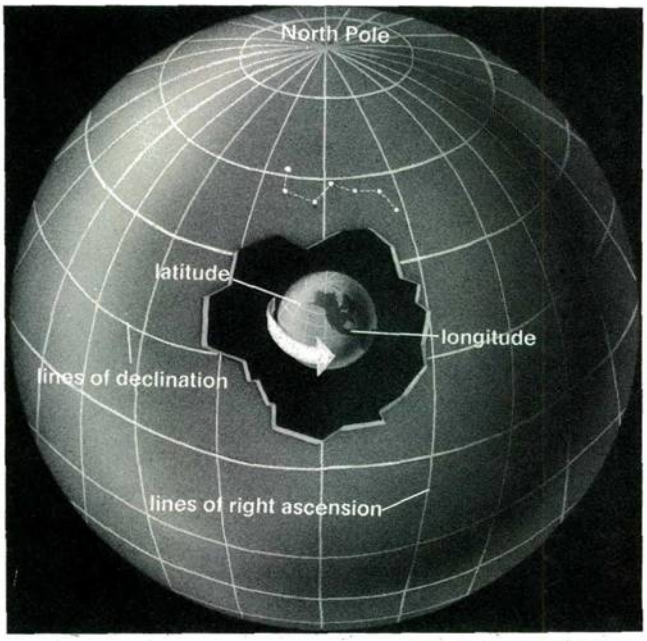
Part 1:

Right Ascension and Declination

by
Richard Berry

The sky coordinates, *right ascension* and *declination*, seem complicated and confusing to many people just getting their feet wet in astronomy, but they aren't. You can learn all you need to know in 10 minutes or so — then go out and read star maps and use your telescope with complete confidence! While it might seem a bit mind-bending at first, you'll soon find you can imagine the gridwork of celestial coordinates shining in the sky, and you'll come to regard the odd little protractors attached to your telescope's axles as handy and useful gadgets.

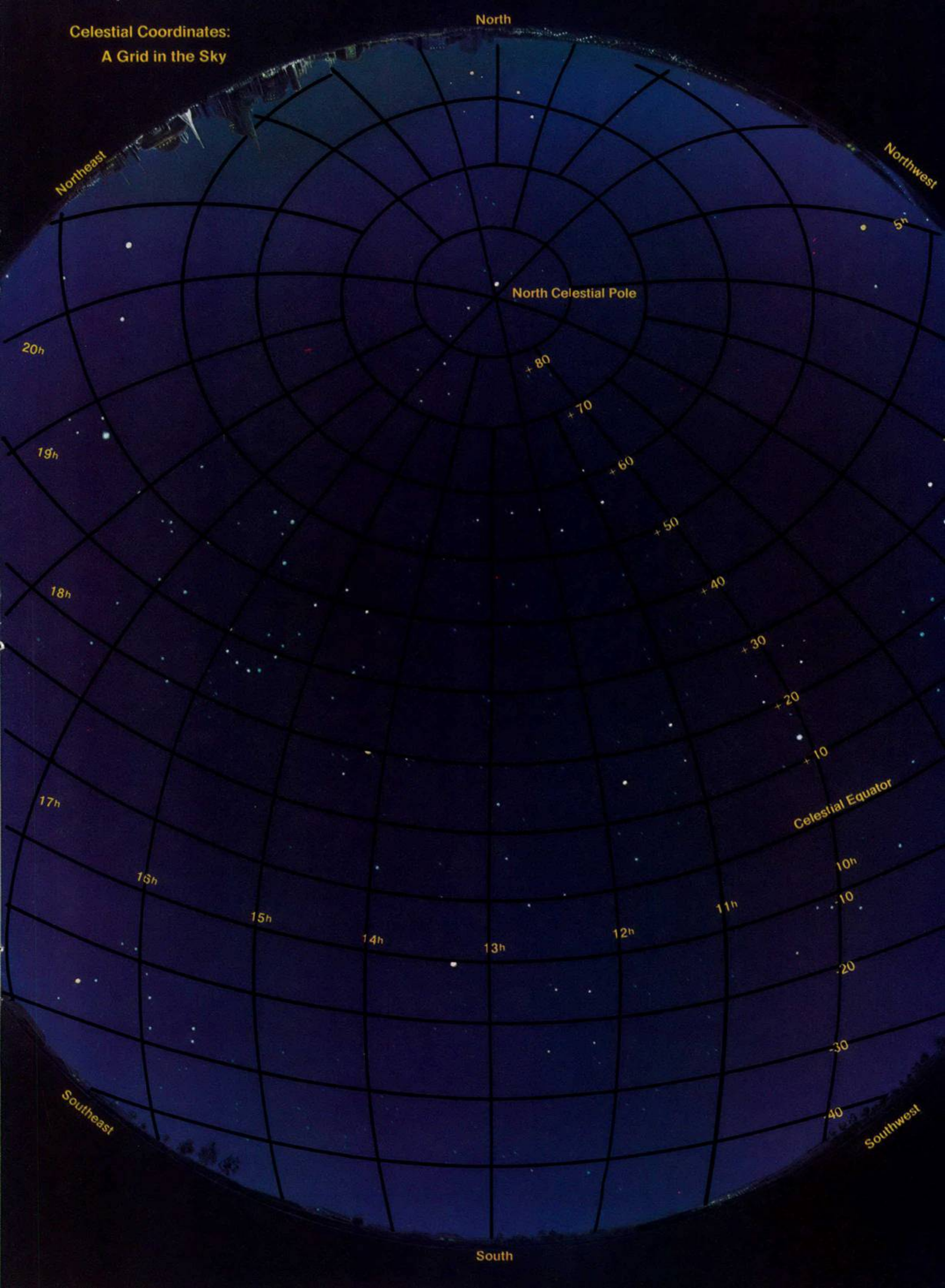
Imagine that somebody took the time to paint all the latitude and longitude lines onto the surface of Earth, and used (if you're taking this seriously) paint that dries very slowly. Now imagine that an invisible crystalline sphere (right out of the Middle Ages) shrank tightly around Earth and all that paint

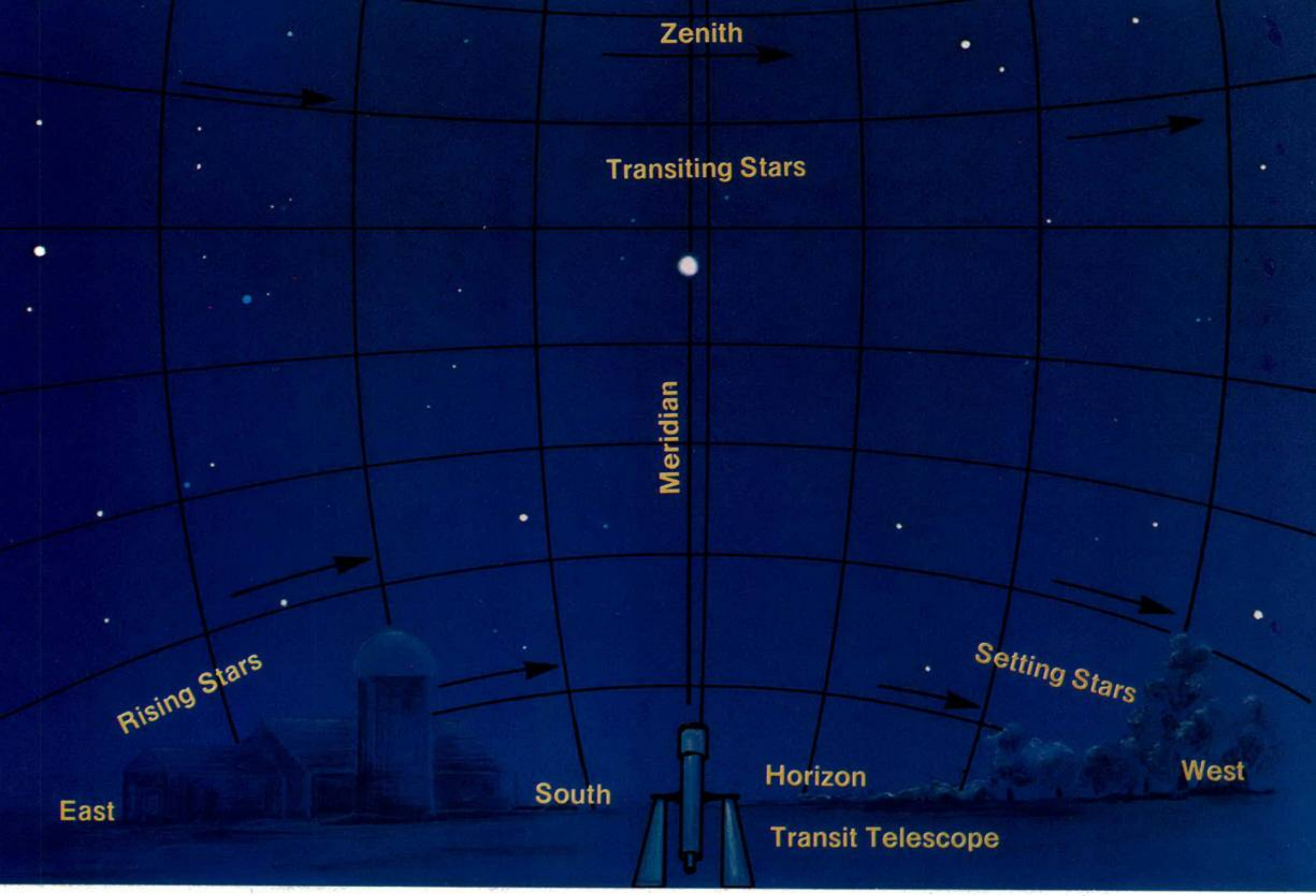


Artwork by Victor Costanzo

Left: From the outside, the lines of right ascension and longitude and those of declination and latitude bear an unmistakable resemblance. Here you see Earth englobed by the celestial sphere. Right: From inside, the grid of celestial coordinates leaps from horizon to horizon, spanning the width of the sky. Imagine yourself under a great domed ceiling, looking up, so that the great grid wraps around you. Artwork by Mark Paternostro.

Celestial Coordinates: A Grid in the Sky


North
Northeast
Northwest
5h
North Celestial Pole
20h
+80
+70
19h
+60
+50
18h
+40
+30
+20
+10
Celestial Equator
17h
10h
16h
-10
11h
15h
14h
12h
13h
-20
-30
Southeast
-40
Southwest
South



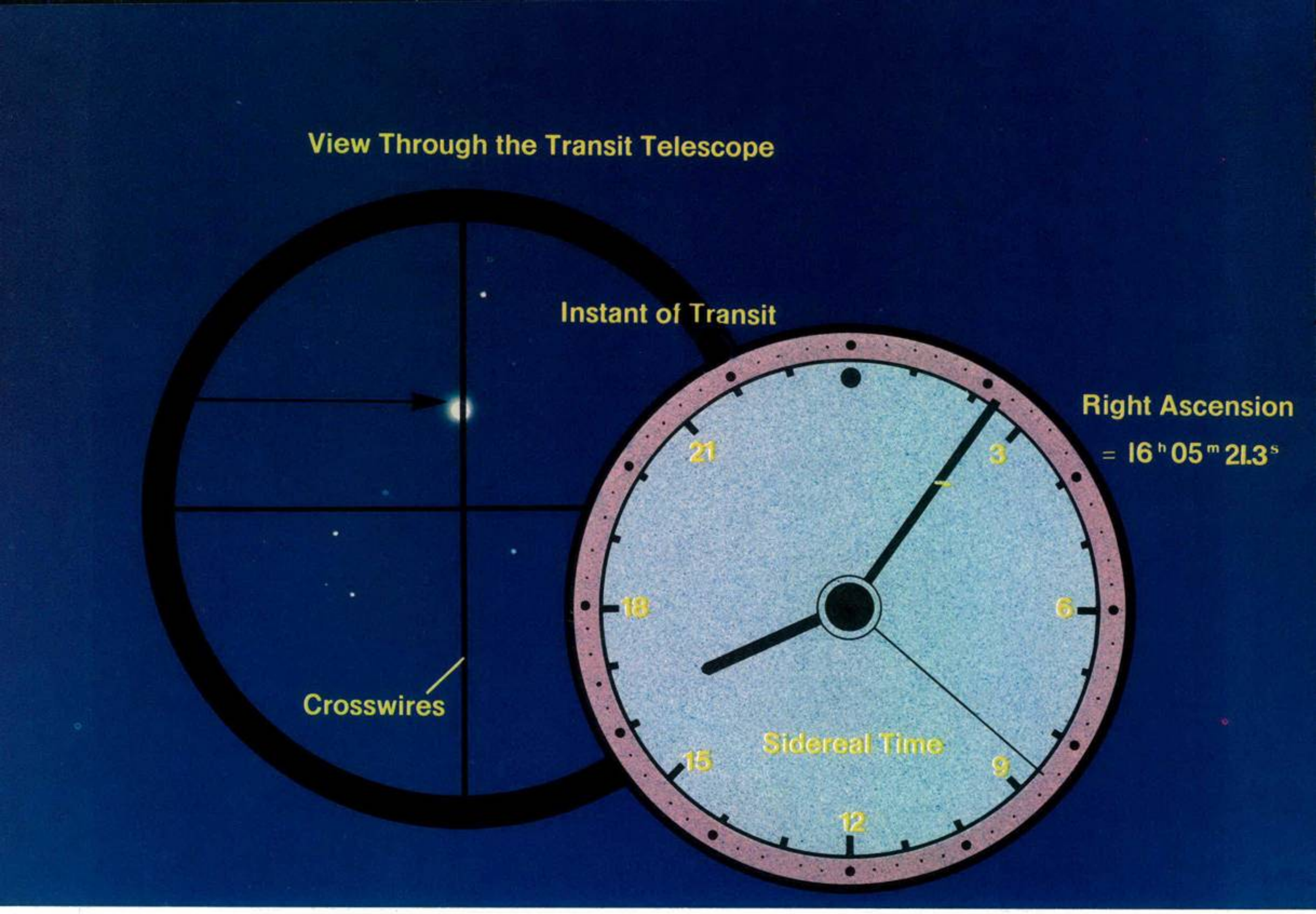
stuck to it; then by some miracle, this unusual crystalline sphere expanded until it became immensely larger than Earth. Now, recover from your sense of shock and look up.

In the sky overhead you would see a gridwork of lines looking something like a globe seen from the inside out. If you looked northward, you'd see the place where all the longitude lines come together at the "pole". Around that pole you'd see circles of latitude. Looking south you'd see partway toward the place where the sphere took the imprint of the south pole, but you wouldn't actually be able to see that area because Earth (which you're standing on) would block your view of it. You'd see the lines of latitude curving around that southern pole, and you'd see lines of longitude curving toward it. If that's not crystal clear, take a look at the illustrations.

Earth's equator is stuck (or painted, if you prefer) to the sky too; it crosses the sky east-west. If you happened to live right on the equator, you could see it by looking straight up. But since you live somewhere north of the equator, you'll have to look somewhat to the south to see the equator. Straight overhead at your latitude — whatever it may be — you'll see your latitude line. If you live at 34 degrees north, you'll see 34 degrees north running right over your head.

Now it's time to change everything's name. Latitude is called *declination* (Dec.), and longitude is called *right ascension* (R.A.). The crystal sphere is called the *celestial sphere*, and the lines you're looking at in the sky are lines of right ascension and declination. You'll soon notice (it just got dark!) that there are stars in the sky too. All you have to do to find the coordinates of a star is carefully read off the numbers (printed small so as not to obscure any stars!) from the lines that run through it. So you could say, for example, that Alpha So-and-so was found at +42 degrees and er, uh 6 hours 33 minutes. Wait a minute — that's the time!

Right ascension is measured as time, except in a few old books and special purpose charts where the more familiar (to most people) degrees are used. The reason is simple: Earth is spinning counterclockwise (as seen from the north pole), so when you look up at the crystal sphere (which *isn't* spinning), it seems to be going clockwise from east to west. Well, the old time astronomers who set up this sytem didn't have lines painted on the sky for their convenience, but they did have some fairly decent clocks. So they measured the *time* a star would pass highest in the sky as its position. Being scholars and familiar with Latin, they called the place where the stars and sun are highest the *meridian*, meaning "middle of the



day". The meridian crosses the sky north to south through the zenith. The sun is highest at midday when it's on the meridian.

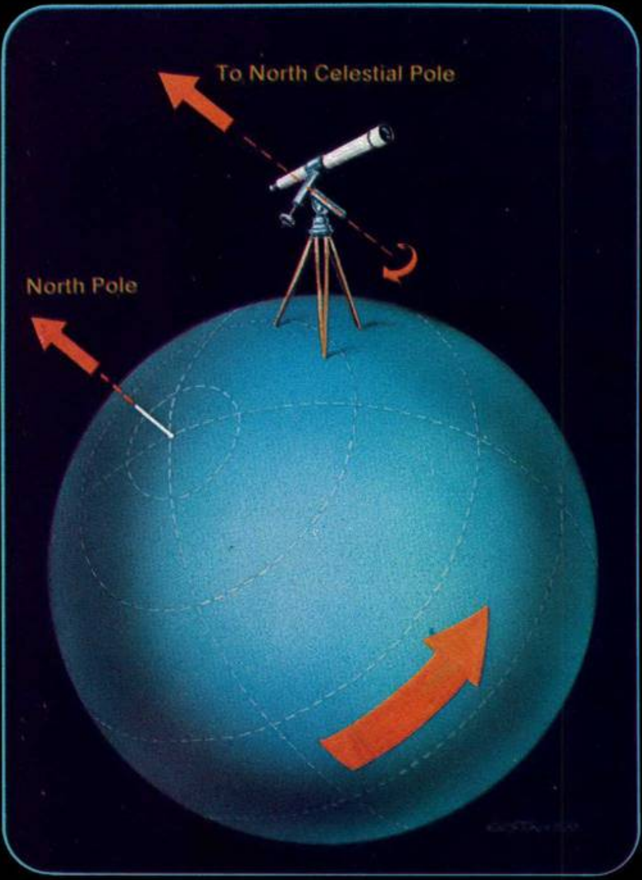
In order to make measuring the places of stars easier, they built special little scopes called *transit telescopes* which could only look at the meridian. Transit means "it crosses" in Latin. Now, we'll use all our new words: When a star transits the meridian, its right ascension equals the time. Ah ha, so you can have a star at 10:45 p.m.? Not exactly, because the time is measured on a 24 hour system and civil time (the stuff you read from your watch) isn't used. A special time — called *sidereal time*, or "stellar" time (again borrowed from Latin) — is used. So you can have a star at 22 hours 45 minutes.

Sidereal time is measured from the sky. If you observe the transit of a star tonight, and again tomorrow night, you'll find that a *sidereal day* — the time between two transits of a star — is 23 hours 56 minutes 4.1 seconds of civil time. Since civil time is based on the sun, and the sun moves against the background of stars, civil time and sidereal time are always getting out of step. You can easily set a mechanical clock to run a bit fast so that it will gain 3 minutes 56 seconds each civil day. Then it will read in sidereal time.

Now you've got the whole picture. Stated in "astronomicalese": When a star transits the meridian, its right ascension equals the sidereal time. Now the only problem remaining is what time to set on your sidereal clock! The easiest way to do that, perhaps, would have been for everybody to agree back in the year 1 that some particularly pretty star was 00^h $00^m 00^s$ and set your watch by it when it transited.

That isn't what happened. They agreed that 00^h $00^m 00^s$ was the spot where the path of the ecliptic crossed the celestial equator in spring. Actually it's a very elegant move, since it simplifies calculations having to do with the positions of the sun and planets. It complicates things a bit when dealing with stars, because there's no handy "zero-zero-zero" spot on the sky. but you can set your clock equally well by any star in the sky, and it's also possible to calculate sidereal time from civil time with reasonable accuracy, so there's really no problem.

Imagine our early astronomer again using his little transit telescope to time stars as they cross the meridian. He's measuring their right ascension. How might he measure declination too? The smart thing to do is to hook a protractor dial to the transit and measure — in degrees this time — where the telescope is pointed. When astronomers started doing



Artwork by Victor Costanzo

this, they measured a star's position as the number of degrees away from the pole — its *polar distance.*

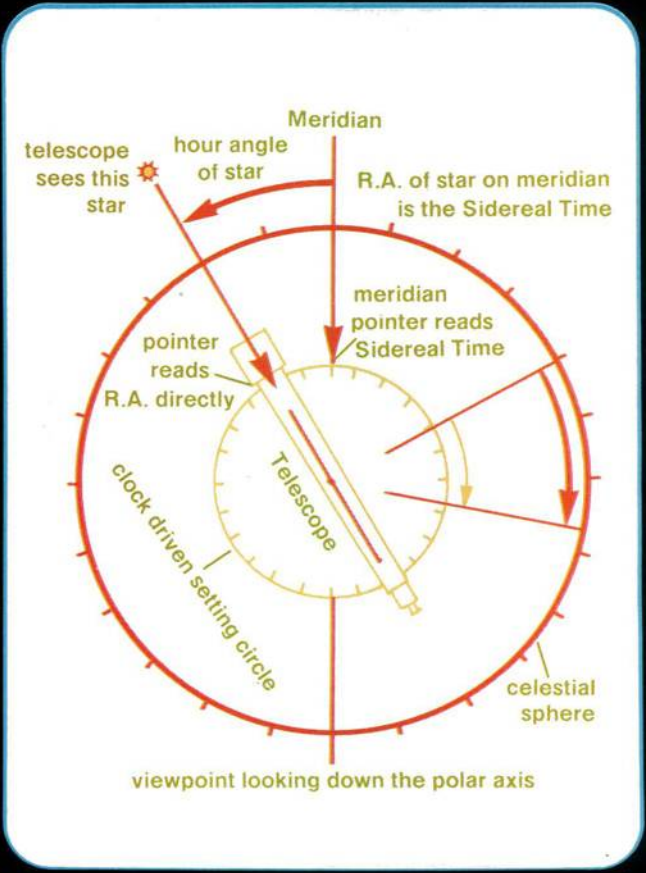
The modern system crept in for the convenience of sailors who navigated by sighting on stars. They used a gadget called a *declining dial.* Declining means "bent away" (in Latin, of course), because the numbers didn't start at the horizon as any proper dial (protractor) would. Declination mimics latitude: The equator is 00°00'00", and the poles are at right angles, or 90 degrees. North is called + for astronomical purposes and logically – represents south. The funny little marks ' and " mean minutes (') of arc and seconds (") of arc. There used to be still smaller divisions (''') and ('''') but they're no longer used. A minute is 1/60 degree, and a second, 1/60 minute.

Now you can see how the whole system works. You can see how the lines of right ascension and declination got there and how they came to be measured by the enterprising astronomers of earlier centuries. You can appreciate, perhaps, how the whole system grew up and how time and locations in the sky got mixed together. If you visit an older observatory you may see an odd little building that can't rotate but has a slit anyhow. That's the transit house, where the transit telescope (which could only point to the meridian) was used. And you can see that's how astronomers used to set their clocks, and indeed, how all the clocks in the world used to be set.

Having mapped all the stars as they crossed the meridian, you may be wondering how to *find* a star. Obviously you could wait until the proper sidereal time rolls around; then set the proper declination on your transit telescope, peer in, and there would be what you wanted to see. It works, but it isn't convenient. Consider for a moment that stars rise, on the average, some six hours before they cross the meridian and set some six hours after. You could easily describe their distance from the meridian in hours and minutes (such-and-such will transit 3 hours 15 minutes from now). In fact, this is exactly what is done. This time-distance is called the *hour angle*, and it's generally described as east (minus) or west (plus) from the meridian. So you could say: Such-and-such has an hour angle 3^h15^m east or -3^h15^m. Then everybody will know that it will cross the meridian in 3 hours 15 minutes. If you say that the hour angle is 5 hours west or $+5^h0^m$, they'll know it crossed the meridian five hours earlier.

The hour angle is simply the difference between your sidereal time and the right ascension of the object: H.A. = S.T. – R.A. If the sidereal time is smaller than the right ascension, the hour angle will be negative, and the object east of the meridian. If you know any two of the three quantities, you can find the remaining one. Thus the following equations are also true: S.T. = R.A. + H.A., and R.A. = S.T. – H.A.

If some clever person built a telescope that could follow the lines of celestial "latitude" across the sky, he could look at stars before they crossed the meridian simply by calculating the hour angle, and then setting his telescope with a protractorlike dial to the proper hour angle. Without further beating around the bush,


Meridian
telescope sees this star
hour angle of star
R.A. of star on meridian is the Sidereal Time
meridian pointer reads Sidereal Time
pointer reads R.A. directly
Telescope
clock driven setting circle
celestial sphere
viewpoint looking down the polar axis

you already know that equatorially mounted telescopes make just exactly the right type of motion. The protractor dial is called a *setting circle*, and the one for right ascension is usually called the *right ascension circle.*

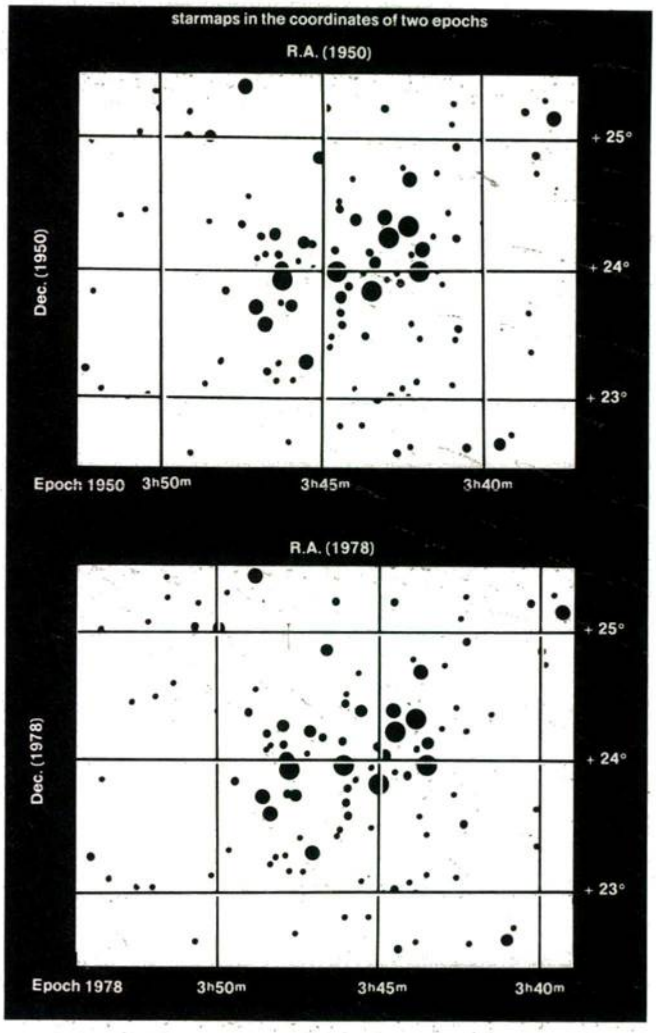
Looking up the time and doing a little calculation whenever you want to look at something could get somewhat tedious, so many modern telescopes incorporate a motor to drive the setting circle and telescope so that the telescope turns at the same rate the stars do. The setting circle can, in fact, act like a little clock if a stationary pointer points to the correct sidereal time. If another pointer (one that turns with the telescope) also points to the dial, so that both pointers read the same time when the telescope is aimed at the meridian, then the moving pointer will read the right ascension directly when the scope is aimed at other places in the sky. The circle acts like an analog computer to do the arithmetic for you.

If the right ascension circle is not clock driven, you can still use the circle with just a bit more work. First, point the telescope at a star whose right ascension you know; then turn the R.A. circle until the R.A. of that star shows beside the pointer. Your circle is then aligned with the sky. Turn the telescope so that the pointer shows the right ascension of the object you want to find and then set the declination by its circle. Lo and behold, the new object ought to be in the field! But within a few minutes the sky will have turned and your circle and the sky will no longer be aligned, so you'll have to repeat the alignment.

How good are setting circles? If the scope is accurately aligned to the pole and the circles are large enough to read accurately, they are a great help in finding things quickly. But even if you have six inch diameter circles, you can't expect miracles. One degree is only about 1/20 inch along the edge of the circle. You can expect to set within 1/2 to 1/4 degree, meaning you will usually find the object if you use a power below 100 or so. For bright objects, you'll probably find that circles aren't worth using. Simply check a star map for the location of the object you're looking for, aim your telescope roughly and you'll be able to quickly spot it in the finder. But for faint objects — especially those too faint to see in your finder telescope — setting circles can be very handy. Now you're ready to go out and use a telescope. And if you look very hard, you'll surely see that gridwork shining on the celestial sphere.

The Tricky Part

The system of right ascension and declination is based on Earth's rotation. Its rotation defines the position of the poles, where the equator is, and the passage of sidereal time. Earth orbits a star — our sun — with a mass of some 1.99 septillion (10^{24}) tons, which tugs on Earth's massive equatorial bulge ever-so-slowly causing the pole to wander, making a full turn every 25,800 years. Circling the spinning Earth is a moon weighing some 73.5 quintillion tons. The moon tugs on Earth's tubby middle and swings Earth's pole through a small wobble in the sky.



Shown above are star maps for the years 1950 and 1978. The coordinates of the stars have changed even though the stars themselves have not, for only the spin of Earth's axis relative to them has changed. You can judge the importance of precession correction for yourself. If you simply want to find a celestial object, you need not correct for precession, but if you are interested in precise positions, it's something you must take into account.

Remember that the zero point for right ascension is the intersection of the ecliptic (the sun's path through the sky) with the equator. If the equator shifts, as it must when the poles move, then the zero point moves too. The result is that all the right ascensions and declinations in the sky are slowly but continuously changing!

The motion amounts to about 50 seconds of arc, or three seconds of right ascension per year, on the average, at the celestial equator. Declination can change by as much as 20 seconds of arc per year too. The change isn't big — Jupiter's disk is usually around 40 seconds of arc across — but it mounts up over the years. In just 37 years, star charts will be off by the width of the full moon! It's a significant enough change that the ancient Greeks knew about it — and they were restricted to eyeball astronomy!

Precession for 100 Years

		Right Ascension																									
		0^h	23^h	22^h	21^h	20^h	19^h	18^h	17^h	16^h	15^h	14^h	13^h	12^h	11^h	10^h	9^h	8^h	7^h	6^h	5^h	4^h	3^h	2^h	1^h	0^h	
	Change in Declination	+33'	+32	+29	+23	+16	+8	0	-8	-16	-23	-29	-32	-33'	-32	-29	-23	-16	-8	0	+8	+16	+23	+29	+32	+33'	**Change in Declination**
NORTH	**+85**	5.1	-1.4	-7.6	-13	-17	-19	-20	-19	-17	-13	-7.6	-1.4	5.1	11	17	23	27	30	31	30	27	23	17	11	5.1	**+85**
	+80	5.1	1.8	-1.2	-3.8	-5.8	-7.0	-7.5	-7.0	-5.8	-3.8	-1.2	1.8	5.1	8.4	10	14	16	17	18	17	16	14	10	8.4	5.1	**+80**
	+75	5.1	3.0	0.9	-0.6	-2.0	-2.9	-3.2	-2.9	-2.0	-0.6	0.9	3.0	5.1	7.3	9.3	11	12	13	13.4	13	12	11	9.3	7.3	5.1	**+75**
	+70	5.1	3.5	2.1	0.8	-0.1	-0.8	-1.0	-0.8	-0.1	0.8	2.1	3.5	5.1	6.7	8.1	9.5	10.4	11	11.2	11.0	10.4	9.5	8.1	6.7	5.1	**+70**
	+60	5.1	4.1	3.2	2.4	1.8	1.4	1.2	1.4	1.8	2.4	3.2	4.1	5.1	6.1	7.0	7.8	8.5	8.8	9.0	8.8	8.5	7.8	7.0	6.1	5.1	**+60**
	+50	5.1	4.4	3.8	3.2	2.8	2.6	2.5	2.6	2.8	3.2	3.8	4.4	5.1	5.8	6.4	7.0	7.4	7.7	7.8	7.7	7.4	7.0	6.4	5.8	5.1	**+50**
	+40	5.1	4.6	4.1	3.8	3.5	3.3	3.3	3.3	3.5	3.8	4.1	4.6	5.1	5.6	6.1	6.4	6.7	6.9	7.0	6.9	6.7	6.4	6.1	5.6	5.1	**+40**
	+30	5.1	4.8	4.5	4.2	4.0	3.9	3.9	3.9	4.0	4.2	4.5	4.8	5.1	5.4	5.8	6.0	6.2	6.4	6.4	6.4	6.2	6.0	5.8	5.4	5.1	**+30**
	+20	5.1	4.9	4.7	4.5	4.4	4.3	4.3	4.3	4.4	4.5	4.7	4.9	5.1	5.3	5.5	5.7	5.8	5.9	6.0	5.9	5.8	5.7	5.5	5.3	5.1	**+20**
	+10	5.1	5.0	4.9	4.8	4.8	4.7	4.7	4.7	4.8	4.8	4.9	5.0	5.1	5.2	5.3	5.4	5.4	5.5	5.5	5.5	5.4	5.4	5.3	5.2	5.1	**+10**
	0	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	**0**
SOUTH	**-10**	5.1	5.2	5.3	5.4	5.4	5.5	5.5	5.5	5.4	5.4	5.3	5.2	5.1	5.0	4.9	4.8	4.8	4.7	4.7	4.7	4.8	4.8	4.9	5.0	5.1	**-10**
	-20	5.1	5.3	5.5	5.7	5.8	5.9	6.0	5.9	5.8	5.7	5.5	5.3	5.1	4.9	4.7	4.5	4.4	4.3	4.3	4.3	4.4	4.5	4.7	4.9	5.1	**-20**
	-30	5.1	5.4	5.8	6.0	6.2	6.4	6.4	6.4	6.2	6.0	5.8	5.4	5.1	4.8	4.5	4.2	4.0	3.9	3.9	3.9	4.0	4.2	4.5	4.8	5.1	**-30**
	-40	5.1	5.6	6.1	6.4	6.7	6.9	7.0	6.9	6.7	6.4	6.1	5.6	5.1	4.6	4.1	3.8	3.5	3.3	3.3	3.3	3.5	3.8	4.1	4.6	5.1	**-40**
	-50	5.1	5.8	6.4	7.0	7.4	7.7	7.8	7.7	7.4	7.0	6.4	5.8	5.1	4.4	3.8	3.2	2.8	2.6	2.5	2.6	2.8	3.2	3.8	4.4	5.1	**-50**
	-60	5.1	6.1	7.0	7.8	8.5	8.8	9.0	8.8	8.5	7.8	7.0	6.1	5.1	4.1	3.2	2.4	1.8	1.4	1.2	1.4	1.8	2.4	3.2	4.1	5.1	**-60**
	-70	5.1	6.7	8.1	9.5	10.4	11	11.2	11	10.4	9.5	8.1	6.7	5.1	3.5	2.1	0.8	-0.1	-0.8	-1.0	-0.8	-0.1	0.8	2.1	3.5	5.1	**-70**
	-75	5.1	7.3	9.3	11	12	13	13.4	13	12	11	9.3	7.3	5.1	3.0	0.9	-0.6	-2.0	-2.9	-3.2	-2.9	-2.0	-0.6	0.9	3.0	5.1	**-75**
	-80	5.1	8.4	10	14	16	17	18	17	16	14	10	8.4	5.1	1.8	-1.2	-3.8	-5.8	-7.0	-7.5	-7.0	-5.8	-3.8	-1.2	1.8	5.1	**-80**
	-85	5.1	11	17	23	27	30	31	30	27	23	17	11	5.1	-1.4	-7.6	-13	-17	-19	-20	-19	-17	-13	-7.6	-1.4	5.1	**-85**
	Change in Declination	+33'	+32	+29	+23	+16	+8	0	-8	-16	-23	-29	-32	-33'	-32	-29	-23	-16	-8	0	+8	+16	+23	+29	+32	+33'	**Change in Declination**

How to Use This Table: Precession is given for a 100 year interval. to find precession for shorter periods of time, take the appropriate percentage of the numbers given in the table. For example, to calculate the 1978 coordinates of the Crab nebula from its 1950 coordinates ($\alpha = 5^h31.5^m$, $\delta = 21°59'$), look in the 5^h column near +20°. The number shown is $+5.9^m$, which is the precession for 100 years. Since 1978 minus 1950 is 28 years, take 28 percent of 5.9 — about 1.7 — and add it to the 1950 coordinate: $5^h31.5^m + 1.7^m = 5^h33.2^m$. The change in declination shown for 5^h is +8' and that shown for 6^h is 0', so you'd expect the correction for 5^h30^m to be about midway between, or +4'. Add 28 percent of the precession, about 1.2' to the 1950 declination: +21°59' + 1.2' = +22°00.2'. Thus the Crab's new coordinates are: $\alpha(1978) = 5^h33.2^m$, $\delta(1978) = +22°00.2'$. If the number in the table is negative, be sure to subtract rather than add it.

This polar wandering is called the *precession*. It causes the *equinoxes* (intersections of ecliptic and equator) to move. Superimposed on the precession is the wobble — called *nutation* — caused by the moon. It's only about 1/5 as large as precession and causes the equinoxes to alternately lead and lag in a 19 year cycle. Nutation can be ignored for all but the fussiest work, because it averages out to zero over each cycle.

It's obvious that you won't miss finding many sky objects with setting circles unless you ignore precession for 50 years or more. But if you're interested in plotting asteroid paths on a star chart, or pinpoint precision in setting a big telescope, you can't ignore precession. Most star charts are still printed with 1950 coordinates (1950 is a standard year). Look in the corners or along an edge or sometimes at the coordinate label, and you'll see R.A. (1950) and Dec. (1950). Sometimes you'll see another notation: α (1950) and δ(1950), meaning exactly the same thing. 1950 is called the *epoch* of the coordinates.

What does "epoch (1950)" mean? In 1950, the given coordinates are those you would have found for a star if you timed its transit across the meridian. Today, in 1978 — or more precisely 1978.287 by mid-April — the sun no longer crosses the equator where it did in 1950. That crossing — the vernal equinox — has moved 23.8 minutes of arc to the west; most of the right ascensions in the sky have increased by about 1-1/2 minutes of time, and declinations have changed as much as 10 minutes of arc in some parts of the sky.

You can correct for these changes quite easily. The table on this page gives precession corrections you can simply add on to the original coordinates. These tables are accurate enough for most purposes, but if you like, you can use trigonometric formulae to find the precession corrections:

$$\Delta(\alpha) = (3\overset{s}{.}973 + 1\overset{s}{.}336 \sin\alpha \tan\delta)N$$

$$\Delta(\delta) = (20.04'' \cos\alpha)N$$

N is the number of years between the original and new epochs. You'll have to convert the right ascension into degrees, find its sine and cosine (remembering to assign the correct sign for the quadrant involved), carry out the operations inside the parentheses, and then multiply by the number of years. The whole calculation should take only a minute or so with a pocket calculator that figures trig functions. These equations are approximations which do not work well close to the celestial poles.

Editor's Note: Next month, you'll read about the types of time used in astronomy and how they are all related to each other.

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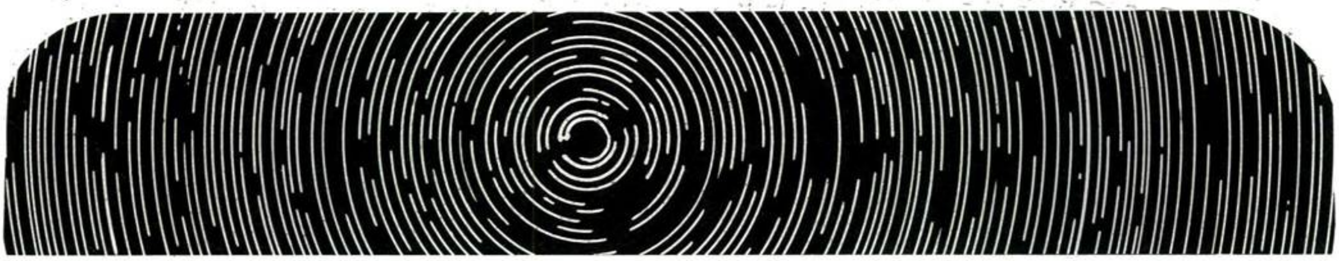


GAZER'S GAZETTE

The "Big Four" Asteroids

by
Frederick Pilcher and Jay Gunter

Anyone who draws to scale a diagram of the orbits of the first five or six planets will note a large gap between the orbits of Mars and Jupiter. As early as 1595, this gap attracted the attention of Johannes Kepler, who wrote "Inter Martem et Jovem interposui planetam" (between Mars and Jupiter I placed a planet).

Few astronomers paid this much attention until 1772, when German astronomer Johann David Titius formulated a rule that mathematically related the placement of the planets to their average distances from the sun. It worked out for the positions of the planets that were known at that time, except for indicating a planet in the gap between Mars and Jupiter. Titius' rule was ignored until it was dramatized in 1778 by Johann Elbert Bode. The 1781 discovery of Uranus followed the formula and gave it a permanent place in the literature, popularly known as "Bode's law". But Neptune, discovered in 1846, violates the rule. Bode's law should be attributed to Titius instead, and in effect is not a law as no physical basis for its existence has been established.

Plans for a search for the missing planet between Mars and Jupiter were suggested soon after the discovery of Uranus, but because of the then-leisurely pace of astronomical research, it was not until 19 years later — in 1800 — that a serious search was begun. At a meeting in Lilienthal that year, through the efforts of Baron Francis Xavier von Zach, Johann Hieronymus Schröter and Joseph-Jérôme Lalande, the ecliptic was divided into 24 zones. Each was assigned to a different observer who was to search his zone for the missing planet.

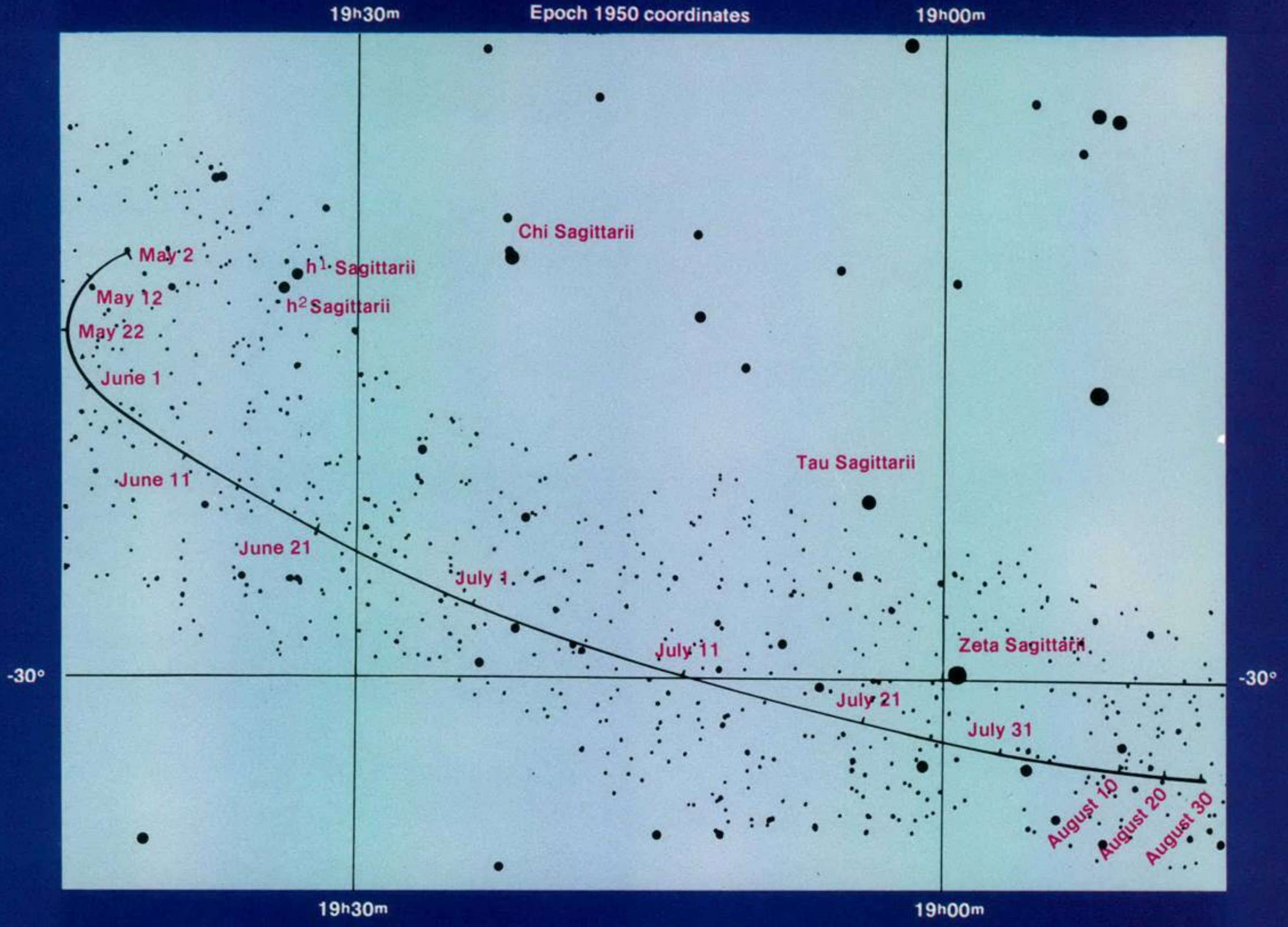
Unaware of these developments, Guiseppe Piazzi, of Palermo, Sicily, had begun compiling a star catalog in 1792. For improved accuracy he measured each star several times with the meridian circle. On Jan. 1, 1801, Piazzi noted a previously unrecorded eighth magnitude starlike object in Taurus. The next night he found that it lay four minutes west and four minutes north of its position the previous night. It moved west until Jan. 11 and then began eastward motion, typical of the end of the retrograde loop of any superior planet. Piazzi waited several weeks before announcing the discovery of "a small comet, unaccompanied by an nebulosity". Due to the slowness of the mails (yes — even slower than today!), Piazzi's object was unobservably close to the sun before the astronomical community was made aware of its existence. At that time the only published formulations on orbit computation were for circular and parabolic objects. During the summer of 1801, Piazzi and others attempted to calculate the orbit from these assumptions, and all realized that the object was probably a small planet rather than a comet. Piazzi named his planet Ceres Ferdinandea after the patron goddess of Sicily and King Ferdinand, but this was soon shortened to Ceres. The calculations by several investigators led to such widely different orbits that Ceres was feared lost.

Karl Friedrich Gauss attacked the problem in September 1801. Gauss was unique among mathematicians as he was both adept at handling complicated expressions of higher mathematics, and able to calculate numbers in his head nearly as rapidly as can be

Above: Ceres, largest of the asteroids, reaches opposition on July 9. The path of the asteroid from May through August follows a downward curve through the constellation Sagittarius. You can use the coordinates listed on the border of this map to trace the *asteroid's progress as it approaches* opposition. Below: The orbit of Pallas is rather curved in appearance as shown here from late April until early August.

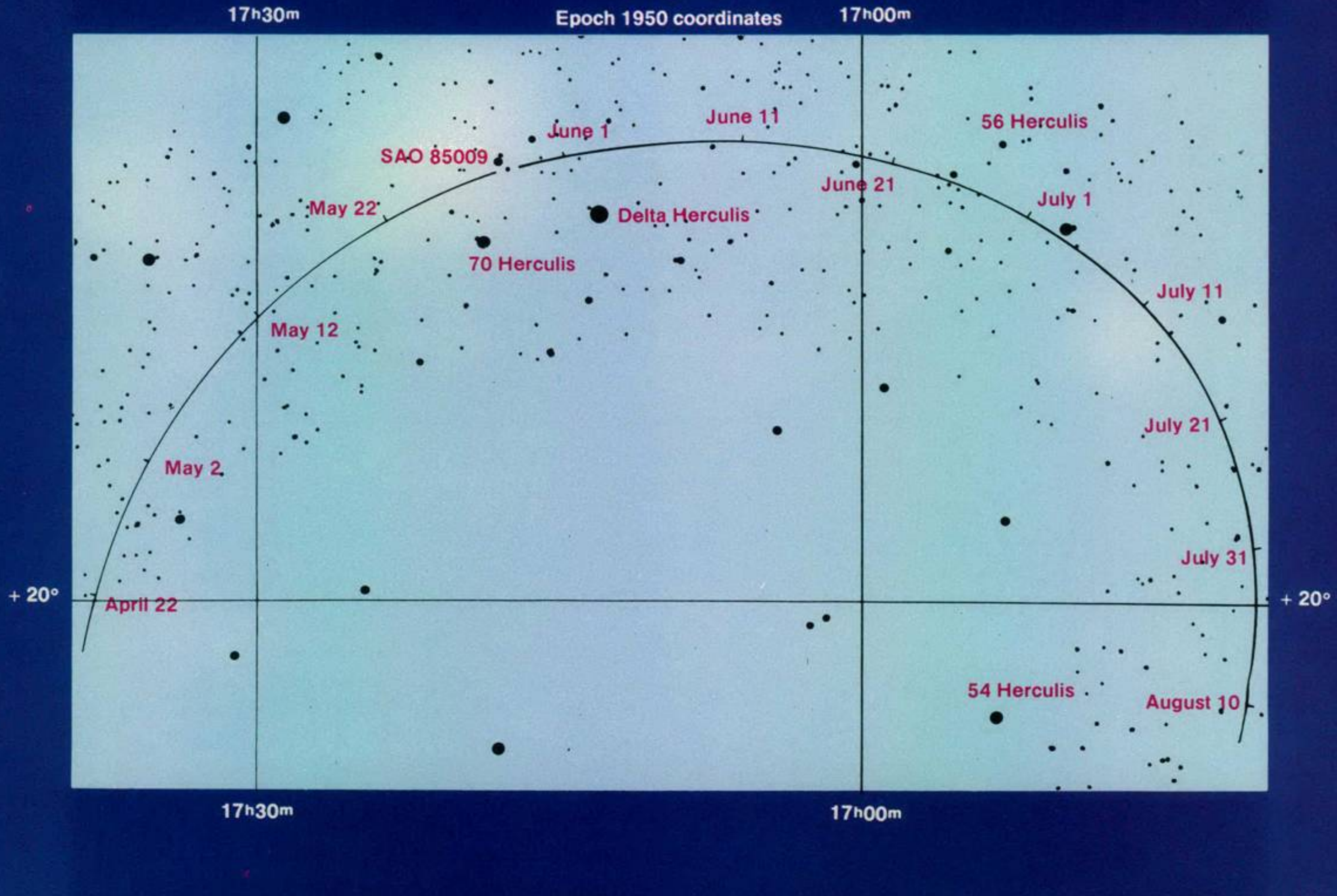
Ceres

Epoch 1950 coordinates


19h30m
19h00m
May 2
May 12
May 22
June 1
June 11
June 21
July 1
July 11
July 21
July 31
August 10
August 20
August 30
h1 Sagittarii
h2 Sagittarii
Chi Sagittarii
Tau Sagittarii
Zeta Sagittarii
-30°
-30°
19h30m
19h00m

Pallas

Epoch 1950 coordinates


17h30m
17h00m
June 1
June 11
SAO 85009
56 Herculis
June 21
July 1
May 22
Delta Herculis
70 Herculis
July 11
May 12
July 21
May 2
July 31
+ 20°
April 22
+ 20°
54 Herculis
August 10
17h30m
17h00m

Observing Asteroids at Opposition

This is *the* summer for observing asteroids; Pallas and Vesta reach opposition in June, Ceres and Juno in July. Asteroids look like ordinary stars in the telescopic field, so the key element here is motion. You'll usually need several nights of observation to confirm the planetlike motion characteristic of an asteroid.

Pallas reaches opposition on June 4 — the first of the four asteroids to do so this summer. At opposition Pallas will be retrograding through south central Hercules; with its 35 degree orbital inclination, it will be nearly 50 degrees from the ecliptic. The asteroid is well toward aphelion, having a visual magnitude of 9.1 and a photographic magnitude of 9.8. Although Pallas is the second largest of the four (380 miles or 610 kilometers), its reflectivity is rather low (see the table). At its opposition on Feb. 10, 1977, Pallas was farther south in contrast to this year's opposition, which is the farthest north it will be for the remainder of this century.

On June 5 Vesta reaches opposition. Brightest of the "big four" asteroids (reflectivity 23 percent), its location in the inner part of the asteroid belt and its high surface reflectivity more than compensate for its small size in the amount of sunlight reflected back to Earth. Because this summer's opposition is near perihelion, Vesta will be about as bright as any asteroid can be at visual magnitude 5.5. In June, it should be dimly visible to the unaided eye for favorably located observers, and easily found with a small telescope or binoculars.

On May 19 you should be able to see Vesta pass 22 minutes of arc north of third magnitude Eta Ophiuchi. On successive nights in late June and throughout July, Vesta's motion can be traced through the asterism of fourth magnitude stars composed of Phi, Chi, Psi and Omega Ophiuchi. Vesta will pass 47 minutes south of Phi Ophiuchi on July 2 about 4 p.m. EDT, and will be only about five minutes northwest of Chi Ophiuchi around 8 p.m. on July 16, traveling southwest near the end of its retrograde loop. Nightly photographs of Vesta in July will be an excellent opportunity to portray planetary motion.

Ceres reaches opposition on July 9. Although it is the largest of the asteroids (625 miles or 1,000 kilometers), its reflectivity of six percent is the lowest. The asteroid has a visual magnitude of 7.1 and a photographic magnitude of 7.7, making it the second brightest asteroid (Vesta is brighter) and brighter than the planet Neptune. Ceres is located in the constellation Sagittarius east of the teapot configuration, and five degrees east of Zeta Sagittarii. It's an easy object to spot with binoculars.

Juno, the smallest and the dimmest of the big four, comes to opposition on July 24. Juno's reflectivity is high (15 percent), but its size (150 miles or 240 kilometers) isn't enough to make it really bright — so if you plan to observe it, you'll need a small telescope. Juno is located in the constellation Aquila about five degrees southeast of Theta Aquilae on opposition night, and has a visual magnitude of 9.2 and a photographic magnitude of 9.9.

Asteroid	Diameter	Reflectivity	Magnitude at Opposition	Distance from Earth at Opposition	Inclination to Ecliptic
Pallas	380 miles (610km)	9%	9.1	218 million miles (349 million kilometers)	35°
Vesta	330 miles (530km)	23%	5.5	106 million miles (170 million kilometers)	7°
Ceres	625 miles (1,000km)	6%	7.1	176 million miles (282 million kilometers)	11°
Juno	150 miles (240km)	15%	9.2	170 million miles (272 million kilometers)	13°

done with today's pocket calculators! Gauss invented a scheme for calculating elliptical orbits, in which the eccentricity is one of the unknowns to be found. He calculated the orbit and ephemeris of Ceres by November, and communicated them to Von Zach (his calculations indicated a mean distance in agreement with Titius' formula). Von Zach saw Ceres on Dec. 7 as one of several starlike objects within 1/2 degree of Gauss' predictions, but had to wait until Dec. 31 to identify the planet by its motion.

Heinrich Wilhelm Olbers was one of many astronomers who followed Ceres in the early months of 1802. To ease the burden of identifying Ceres among the stars, he prepared charts of stars along Ceres' predicted path. On March 28, he discovered a new starlike object crossing the path over which Ceres had just passed. Moving rapidly northward, Olbers thought this object was a comet. After several weeks of observations, Gauss was able to calculate an orbit which showed Olbers' object to be another planet with a remarkably large inclination to the ecliptic of 35 degrees. Olbers named his planet Pallas.

Sir William Herschel of England was first to call attention in 1802 to the existence of a new class of objects in the solar system with planetlike orbits, but entirely stellar in appearance, unresolvable into disks even with his best telescopes. Because of their starlike (as opposed to planetary) appearance, Herschel coined the word "asteroid", from the Greek words meaning "starlike". Use of this term versus the synonymous "minor planet" is an emotional issue among some astronomers today, and both terms remain in frequent use.

Observation of the asteroids required star charts with an unprecedented number of stars in order to distinguish the asteroid from nearby stars, so stellar cartography received an immediate boost. Karl Harding, an assistant to Schroter at Lilienthal, was compiling an atlas of 120,000 stars (**Atlas Novus Coelestis**) when he discovered, on Sept. 1, 1804, an eighth magnitude moving object in Pisces. Harding named his planet Juno, and within a few weeks Gauss had calculated its orbit.

Soon after discovering Pallas, Olbers noticed that the orbits of Ceres and Pallus nearly intersected in Virgo and Cetus. He hypothesized that Ceres and Pallas were fragments of a shattered larger planet, and that more should be found. The orbits of all the pieces, Olbers thought, should pass through the same point in space where the catastrophe occurred. Credence was afforded this theory by Harding's discovery of Juno. Accordingly Olbers began searching the regions in Virgo and Cetus where the orbits came close together, and through which other asteroids might be expected to pass. On March 29, 1807, Olbers found a moving starlike object of sixth magnitude, which he named Vesta. (This was the first premeditated discovery of an asteroid.)

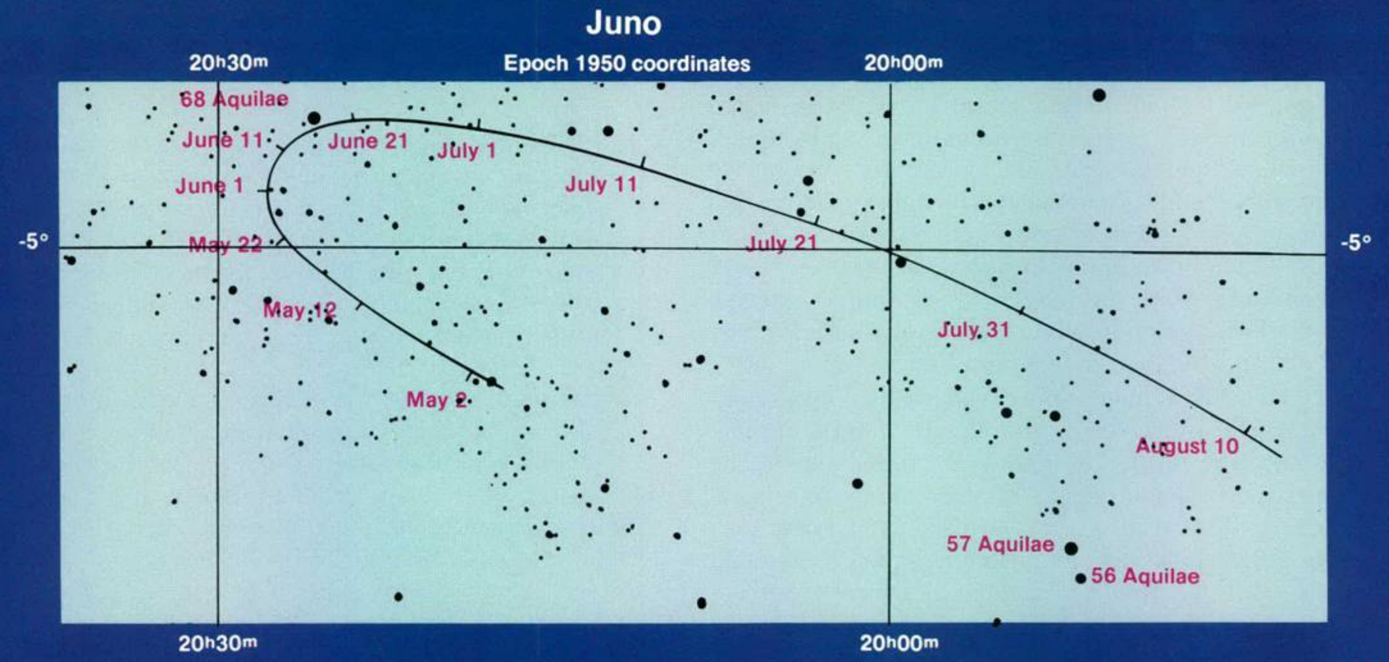
Pallas Occults A Star

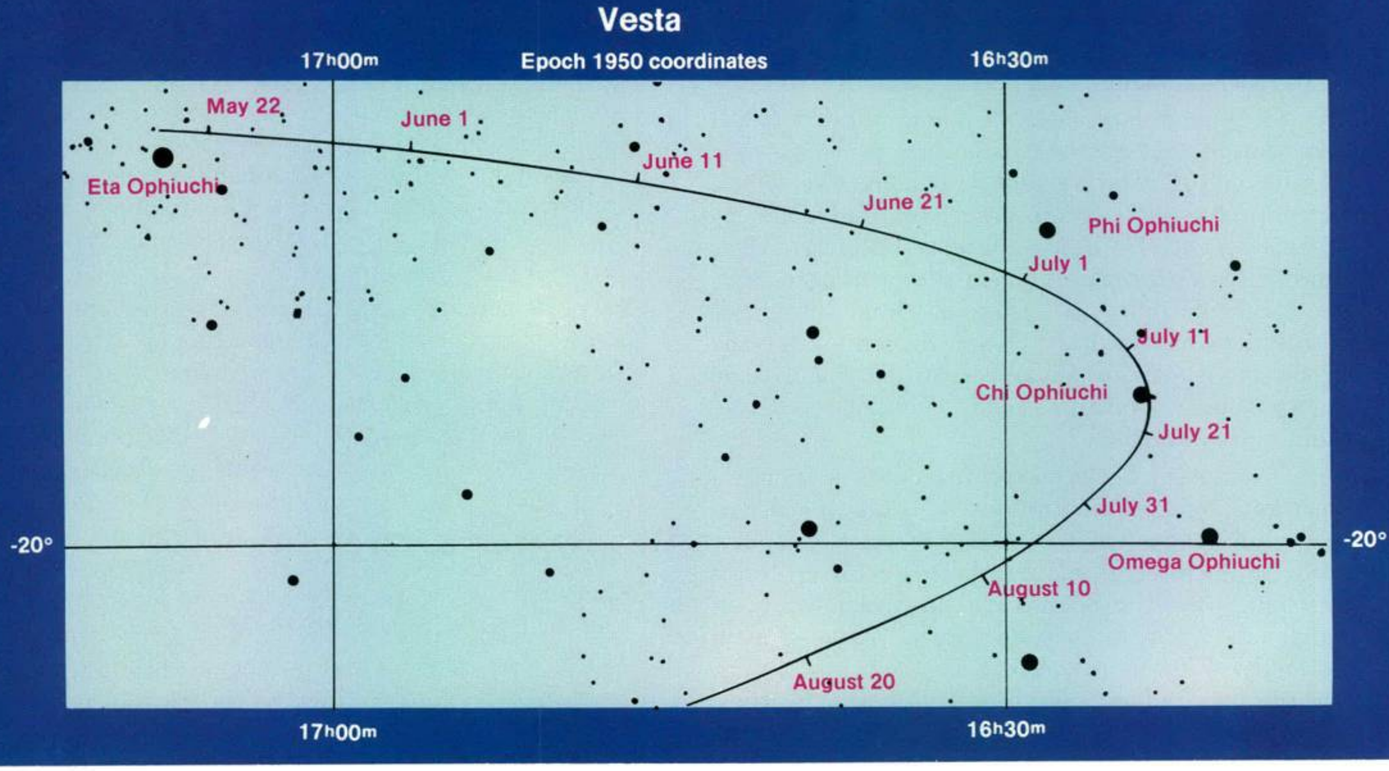
The night of May 28-29 will present an excellent opportunity for observers to advance our knowledge of fundamental astronomy. Pallas (visual magnitude 9.1) will occult the 9.5 magnitude star SAO 85009, at right ascension 17 hours 17 minutes 6 seconds, declination +25 degrees 29 minutes, as shown on the accompanying finder chart. Timing of the duration (specific times are mentioned later) of the occultation with a stopwatch will provide a direct measurement of the diameter and cross-section of Pallas — information never before obtained! For about a half hour before and after closest approach, Pallas and the star will be unresolvable and appear as one. If an actual occultation occurs there will be a slight dimming of their combined light to the brightness of Pallas alone. If you observe, give the longitude and latitude of your station (at least to the nearest minute), and duration of the occultation in seconds of time. Negative observations (that is if no occultation is seen) outside the occultation track should also be reported. It's hoped that hundreds of observations will be made, as this much information will permit not only measurement of the diameter but also the observation of surface features along the limb.

The nominal center of the path runs approximately from Portland, Maine, through Ottawa, Ontario, across Lake Superior, and then west roughly along the United States-Canada border. The width of the path will equal Pallas' diameter — about 370 miles or 600km — and maximum duration will be about 43 seconds. Because of uncertainties in the positions of both star and asteroid, the actual path may lie several hundred miles north or south — so if you live within 1,000 miles of the predicted path, try observing.

The shadow of the star will sweep westward from the Atlantic Ocean to the Pacific from about 5:21 to 5:26 UT on May 29. Approximate times will be 1:21 a.m. EDT on the Atlantic coast, 1:22 a.m. EDT in the vicinity of the eastern Great Lakes, 12:23 a.m. CDT near western Lake Superior, 12:24 a.m. CDT in western North Dakota and Saskatchewan, 11:25 p.m. MDT in Western Montana and Alberta, and 10:26 p.m. PDT along the Pacific coast. If you live in the northern half of the U.S. or in these provinces of Canada, mark the night of May 28-29 on your calendar and look for the occultation. And be sure to send the results of your observations to ASTRONOMY, Pallas Occultation Results!

The discovery of Vesta, however, led to doubts of Olbers' hypothesis of a shattered planet. Gauss' orbital calculation indicated a much smaller semimajor axis than the first three, meaning that it did not even come close to intersecting their orbits. Gauss' calculations, begun in 1802, of the perturbations produced by the gravitational attraction of Ju-


Juno
20h30m
Epoch 1950 coordinates
20h00m
68 Aquilae
June 11
June 21
July 1
June 1
July 11
-5°
May 22
July 21
-5°
May 12
July 31
May 2
August 10
57 Aquilae
56 Aquilae
20h30m
20h00m


Vesta
17h00m
Epoch 1950 coordinates
16h30m
May 22
June 1
June 11
Eta Ophiuchi
June 21
Phi Ophiuchi
July 1
July 11
Chi Ophiuchi
July 21
July 31
-20°
Omega Ophiuchi
-20°
August 10
August 20
17h00m
16h30m

Above: Juno, situated in the constellation Aquila, reaches opposition on July 24. This map shows the path of the asteroid from late May to early August. Below: Vesta, at magnitude 5.5, is the brightest of the big four asteroids this year. Vesta is located in the constellation Ophiuchus; its path is shown from early May until the beginning of August. On May 19, Vesta will pass approximately 22 minutes north of Eta Ophiuchi. This is a very favorable opposition — Vesta is the brightest and closest it can get. The next time observing conditions will be this favorable will be 1989.

piter (and to a lesser extent by the other major planets) showed that the orbits change continually in space, and after several thousand years the fragments of any actual disruption would miss the disruption point by many millions of miles.

The tremendous variety, especially in semimajor axes, of asteroid orbits known today has demolished Olbers' hypothesis. Perturbations reorient the orbits but, except for unusual asteroids which make close approaches to the major planets, change the semimajor axes only by small amounts. Instead of being fragments of a shattered planet, the asteroids represent a planet whose formation could never be completed, perhaps because of the low density of material in the asteroid belt. Ceres, Pallas, Juno, Vesta, and many other larger asteroids are true parent bodies, nearly intact except for surface cratering. Over several billion years, collisions among the parent bodies have produced enormous numbers of small fragments. The relative number of parent bodies versus collision fragments among slightly over 2,000 permanently numbered asteroids is controversial even today. But the concept of a large number of parent bodies which never collected into a single, ordinary sized planet is universally accepted. ◆

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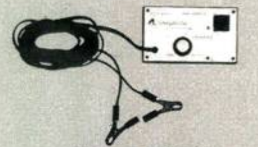

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ASTRONOMY REVIEWS

The Beginner's Guide to the Skies

by C.H. CLEMINSHAW

152 pages, hardcover, $7.95
Thomas Y. Crowell Company (1977)

Subtitled "A Month-by-Month Handbook for Stargazers and Planet Watchers", this latest work by Dr. Clarence Cleminshaw contains an immense amount of information for both beginning and advanced observers who enjoy stargazing with the unaided eye. It gives, for example, the location and/or aspects of the sun, moon and five bright planets for as far into the future as the late 1990s in some cases! A series of 24 star maps — one for the evening and one for the morning sky each month — has listed below them the locations of Venus, Mars, Jupiter and Saturn every year through 1988.

It is these superb little maps that are perhaps the most useful feature of this handy book. Printed with white stars and connecting lines on a black background, they are very clear and uncluttered. Finding your way around the sky for the first time is a cinch using these as a guide. For added help, the "Big Dipper method" of locating the constellations is presented in perhaps the best demonstration of this technique yet.

Adding to the fun is a unique and well planned constellation quiz, complete with 40 unlabeled star pattern diagrams. Those able to identify all of these correctly from the descriptions provided will be well on their way to a comprehensive knowledge of the night sky. There are also chapters giving the meanings of 40 prominent star names and the mythology of the better known star groups.

On the negative side, many of the diagrams in this book — such as those dealing with twilight, solar time and the path of the sun across the sky — seem quite complicated and are apt to scare off many beginners from reading it. Also, it would have been nice to see mention of at least some naked eye and binocular objects visible within the various constellations — sights like the Orion nebula, Double Cluster and Andromeda galaxy, and samples of the host of variable and double stars.

Cleminshaw's new book is masterfully done but has somewhat of a formal "textbook" air about it. Those preferring a more inspirational approach to stargazing should probably supplement it with some of the observing "classics". Together, such a combination of the old and new would provide an introduction to the workings and beauty of the firmament that is simply unbeatable! *James Mullaney.*

* * *

Deep Sky Objects A Photographic Guide for the Amateur

by JACK NEWTON

160 pages, paperback, $9.50
Gall Publications Inc. (1977)

Astrophotography Near City Lights

by JOSEPH A. COCOZZA

48 pages, paperback, $12.00*
Edmund Scientific Co. (1977)

Sometimes people working independently, without being aware of each other, come up with the same idea at the same time. This has happened here: Two astrophotographers — one a Canadian living north of Toronto, and the other a Philadelphian living only five miles from that city — have both produced photo albums of deep sky objects taken with 12 inch Newtonian telescopes. Happily, though, both books are primarily picture books, and the authors have taken complementary approaches.

Newton's book is an atlas of Messier objects, complete with star charts for easy location of virtually every object on that famous list, plus a bonus in NGC objects. Cocozza's book provides much valuable information for city bound astrophotographers: tips on film, filters, guiding and printing, as well as beautiful reproductions of 32 of the more spectacular deep sky objects.

Such an ambitious book has been undertaken at least once before by a German, Hans Vehrenberg, but his photographic survey of the Messier catalog is no longer available. Curiously, Vehrenberg tried another approach entirely, concentrating on providing a scientific background for each object. The photos in both new books were taken with telescopes of considerably longer focal length, and hence provide more detail in the individual objects.

Both books are expensive for their size — but then neither is a mass marketed, mass produced book. Where else besides Newton's book can you find a complete photographic Messier catalog, with charts, ready to carry to the telescope with you? Where else can you find some of the photographic tips that Cocozza, a professional photographer for over 30 years, has to offer, plus a portfolio of astrophotographs? Besides, when you stack the cost of these books against the high cost of wasted film and photographic chemicals and paper, they don't seem so expensive after all!

Both books could have been better. **Deep Sky Objects** suffers from hard-to-see stars on the star charts. With a red filtered flashlight (the usual omnipresent companion of a deep sky observer), the faint stars on the charts are too tiny to see. It nevertheless is a valuable reference, despite its shortcomings as a star atlas.

Astrophotography Near City Lights is underedited. The text could use more basic background material, and needs to be better presented. But the information is there, and the pictures in the book should serve as encouragement to other city bound astrophotographers. *Richard Berry.*

* * *

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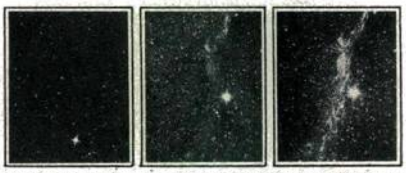

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ASTRO-NEWS

Latest News From the World of Astronomy

X-Ray Studies Identify Intergalactic Clouds

Huge clouds of superhot, primordial intergalactic gas (IGG) may have been identified by x-ray astronomers at the Harvard/Smithsonian Center for Astrophysics at Cambridge, Mass.

Research teams under NASA contract obtained a "mountain" of data from the Small Astronomical Satellite (SAS-I, later renamed UHURU), launched from Kenya, Africa in 1970. Drs. Stephen Murray, William Forman, Christine Jones and Riccardo Giacconi have suggested that these clouds of hydrogen may contain enough mass to gravitationally bind clusters of clusters of galaxies into the largest aggregate of matter known in the universe: *superclusters*!

The IGG was identified based on data in the fourth UHURU catalog of x-ray sources, an x-ray map of the universe compiled by L. Commsky, P. Julien, G. Peters, H. Tananbaum and the researchers already mentioned.

Over 300 x-ray sources are catalogued, and many have been tentatively identified. The three x-ray sources now associated with superclusters and clouds of IGG were the end product of elimination. "Many extragalactic x-ray objects are recognized sources such as quasars, Seyfert galaxies, active galaxies, or single clusters of galaxies," said group spokesman Murray, in a recent interview.

The existence of possible superclusters has been suspected by astronomers for some time. The optical appearance of galaxy clusters indicates a higher order clustering pattern (see "Rich Clusters of Galaxies", ASTRONOMY, October 1977), but there was not enough apparent mass to physically hold these so-called superclusters together. Now, like a blind man slowly regaining sight, the "missing mass" may have been "seen" for the first time and a major mystery of cosmology solved.

Some basic parameters of this suspected IGG will help in describing these previously unknown x-ray sources. Their angular diameter is up to 50 megaparsecs (about 150 million light-years). Temperature is an incredible 100 million degrees Kelvin! Density is a tenuous 10^{-5}cm^{-3}. X-ray luminosity is approximately 7 x 10^{45}ergs/second. Distance from Earth is approximately 400 million light-years, or a redshift factor of 0.20.

Murray estimated that about twice the mass previously recognized could be contained in IGG. This is enough to bind the superclusters gravitationally, but not enough to "close" the universe.

Other questions remain unanswered. Why is the IGG so hot? "We really have no positive answer. Remember, this is probably primordial gas that was present when the universe was born," said Murray. "One theory being discussed is the existence of large numbers of quasars in the younger universe. These earlier quasars could have produced enough initial energy to heat these huge clouds, but we're just guessing at this point," he said.

Because of this high temperature, the IGG x-ray emission dominates all other radiations such as optical and radio. This is the main reason the IGG remained hidden until now.

As previously mentioned, the most distant supercluster detected thus far is about 400 million light-years from Earth. This is actually the limit of sensitivity of UHURU. In August 1977, the first High Energy Astronomy Observatory (HEAO-A) satellite was launched into Earth orbit. In November 1978, HEAO-B will hopefully follow. The sphere of the x-ray universe can then expand to about 0.50 redshift factor (over one billion light-years)!

"When we get our drawing board ideas on the Space Shuttle in the 1980s, we'll be able to reach out to a 10.0 redshift factor!" Murray replied, when asked about future x-ray investigation plans.

HEAO observation could detect the remaining missing mass required to close the universe. However, if the mass is simply not there, present theories say that expansion will continue forever. A closed universe will eventually fall back onto itself, forming a single sphere of superdense matter.

Among the regions of space to be searched will be *intra*galactic space (the space between individual galaxies). Over half of all known galaxies are found in sets of two or more to form clusters. Murray reported evidence of intragalactic gas in dense clusters of galaxies. Should there be equal amounts of gas in these less dense groups, there would be about two times more mass than accounted for by traditional optical and radio telescopes.

"The real trick in locating gas in intragalactic space is to be sure the x-rays are not being emitted by individual galaxies. HEAO should give us a much clearer picture," said Murray.

Is there any aggregate of matter larger than the IGG bound superclusters? Murray said that many fellow researchers believe superclusters are at the top of the cosmic hierarchy.

It is premature to speak about the largest supercluster, but with the increased range of HEAO, a much larger number of superclusters will no doubt be found. It is interesting to note that the previous record holder for largest size was a radio galaxy with a recognizable "radio tail" 18 million light-years long. A radio galaxy emits most of its energy in the form of radio waves.

The concept of superclusters stretches the imagination — but who can even imagine what may be discovered 20 billion light-years from Earth? Through the use of UHURU and HEAOs A and B, the x-ray eye of the astrophysicist is not blind anymore!

AAT: International Telescope

About 250 miles northwest of the sprawling city of Sydney, Australia lies Siding Spring Mountain, home of several telescopes. Dominating the scene, and visible from 30 miles away, is the gleaming dome of the Anglo-Australian telescope (AAT), the world's fourth largest eye on the universe.

The mountain site is situated in the Warrumbungle National Park, a region of eroded and shattered volcanic peaks that are thrust up in the featureless plains of New South Wales. Beyond lies bush country and thousands of miles of uninhabited desert. Australia has no really high ranges of mountains, and this wooded hill was chosen by Bart Bok (until recently professor of astronomy at the University of Arizona) as a suitable place to build an observatory for the Australian National University. A mere 3,800 feet (1,390 meters) above sea level, it is the home of ANU instruments, as well as the United Kingdom's Schmidt telescope.

Australia and Britain have a long history of collaboration in astronomy. As early as 1769, British explorer Capt. James Cook sailed for Tahiti to observe Venus as it passed across the face of the sun. He went on to Austrailia, discovering Botany Bay.

Ten years ago, British and Australian astronomers agreed on a joint project to construct a new telescope. The British, frustrated by cloudy skies, needed a large instrument in a climate suitable for astronomical observations. At the time all large telescopes operated in the northern hemisphere. Consequently, relatively little was known about the stars and galaxies visible in southern skies. Observing from the southern hemisphere has its advantages: The central sections of the Milky Way come into better view, and the two Magellanic Clouds are easily accessible to detailed study. Visible to the naked eye as hazy patches of light, the Magellanic Clouds are the nearest galaxies to our own Milky Way. Beyond our nearest galactic neighbors, countless millions of distant galaxies beckon to be catalogued, photographed and analyzed, in our perpetual quest to understand the nature of the universe.

The exciting prospect of sweeping virgin skies of the far south — long neglected because most astronomers live in the northern hemisphere — led the two nations to join forces. Both governments ultimately granted $15 million for construction of the telescope, dome and equipment.

The AAT measures 153 inches (3.9 meters) and is the fourth largest in the world. (The Kitt Peak National Observatory Mayall telescope has a 158 inch mirror, but the edges are turned down so they have to mask it off, therefore using only 150 inches. In terms of the actual usable portion of the mirror, the AAT is fourth; when only considering *mirror* size, it is fifth largest behind the Mayall telescope.)

The Anglo-Australian telescope is part of a new generation of instruments, conceived in the early 1960s, with reflecting mirrors about 150 inches (3.8 meters) in diameter. Telescopes of this size are considerably cheaper to build than a 200 inch. With modern instrumentation the slight loss of light capturing power isn't too serious when traded off against the reduction in cost.

AAT *continued on page 61*

What It's Like to Use the AAT

by

Simon Mitton

In conjunction with radio astronomers at the University of Sydney and optical astronomers from the University of Cambridge, I engaged in a short project to measure the redshifts of quasars. We made an application to use the telescope and the image-dissector scanner to get quasar spectra. The committee, whose members are also astronomers, assigned us four nights for this project.

A few weeks later I set out on the 25 hour flight from London to Sydney. Two movies, five in-flight meals, and 14,000 miles elapsed before I met my colleague John Whelan at Sydney's international airport. (Whelan is on a one year leave from Cambridge University.)

The scientific staff of the Anglo-Australian Observatory is based in Sydney (in bare concrete offices), 250 miles from the telescope.

One week was enough for Whelan and me to finish preparing our program. We then flew with sheep farmers and school children to Coonabarabran airstrip, 26 miles from Siding Spring. After a short drive through gum trees and grazing land, we arrived at a lodge on Siding Spring mountain, where we stayed for a week.

The telescope took several hours to set up for our run. Whelan, who had used the equipment several times, explained as much as he could in the available time. By dusk the night assistant was setting on a standard star for calibration. Our run had begun.

To a newcomer the control system is amazing. We merely gave the computer the right ascension and declination of each quasar and it did the work. With pleasure I watched the television monitor as object after object was positioned almost exactly on the entrance aperture of the spectrograph. In the previous weeks I had measured their coordinates at Cambridge to 1/10 second of arc.

I watched the spectrum building up bit by bit on another monitor. After a half hour we ran a computer program and got our spectrum plotted out, as a graph with intensity against wavelength. All the time the instrument acquired further data. The first three objects were disappointing; they turned out to be very faint stars, not quasars.

But then we found something different. Within five minutes we could see on the monitor strong spikes at particular wavelengths; we were certain this was a quasar with strong emission lines in its spectrum. After 15 minutes the results thus far were plotted out and the wavelengths measured with a 10 cent ruler. Whelan did the arithmetic on a pocket calculator, and worked out the redshift of the quasar. We knew the answer *before* the observation was finished! Since our objective on this occasion was to get only redshifts, we terminated the observation ahead of schedule and got the computer to slew the telescope to the next object.

During the night there was time to walk around the gallery outside the dome. After getting dark-adapted, we could see the Magellanic Clouds, the Southern Cross, Coalsack, a globular star cluster and a beautiful glow I realized must be the zodiacal light. Orion was upside-down (according to my usual orientation), which was rather confusing!

Eighty miles away light shimmered dimly in a small township. There are only five significant towns in the 20,000 square miles visible beneath and beyond!

Simon Mitton is secretary of the Institute of Astronomy, University of Cambridge, England.

AAT *continued from page 60*

Other facilities in this class are the Mayall telescope at Kitt Peak, the Cerro Tololo telescope in Chile, and the 142 inch European Southern Observatory reflector, also in Chile.

Among these new telescopes — part of the revolution in astronomy reported in ASTRONOMY, November 1977 — the AAT is unique in two respects. It has the best available equipment in terms of computer control, and is the only one jointly managed by two countries on opposite sides of Earth!

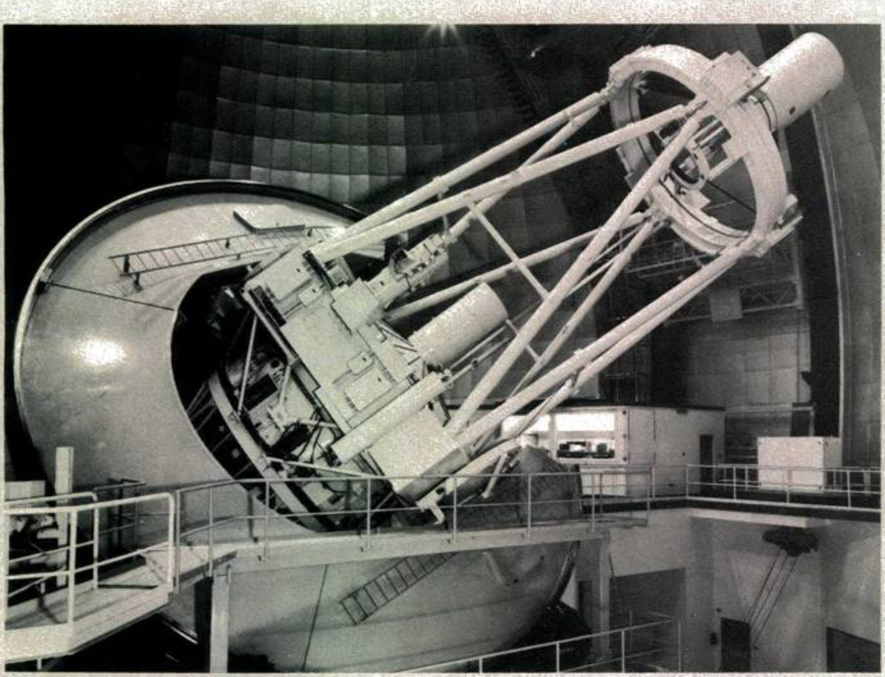
The optical system of the telescope gives high quality images at the Cassegrain focus, where much spectroscopy is done, as well as a wide field of view at the prime focus. The mirror is made of Cervit, a ceramic material which expands or contracts very little as the temperature in the dome changes. When cast, it was the largest Cervit mirror blank in existence. Use of this low expansion glass is essential for achieving the sharp images that professional astronomers now demand.

But a nearly perfect optical system is useless unless the telescope is skillfully controlled during an exposure. Slight drifts in the telescope position, for example, blur an image just as an unsteady hand does with an ordinary camera. Suppose the astronomer is obtaining a spectrum: The job takes much longer if the telescope drifts because then not all the starlight enters the spectrograph. Most telescopes are continuously guided by an astronomer, which is very tiring. On the AAT the tedious task of guiding, as well as all other telescope functions, is handled by a computer. Total computer control leaves the astronomers free for concentrating on the results as they are obtained. It's not unusual to modify an observation program in response to data obtained only minutes before. Automatic control vastly improves the efficiency of this giant telescope.

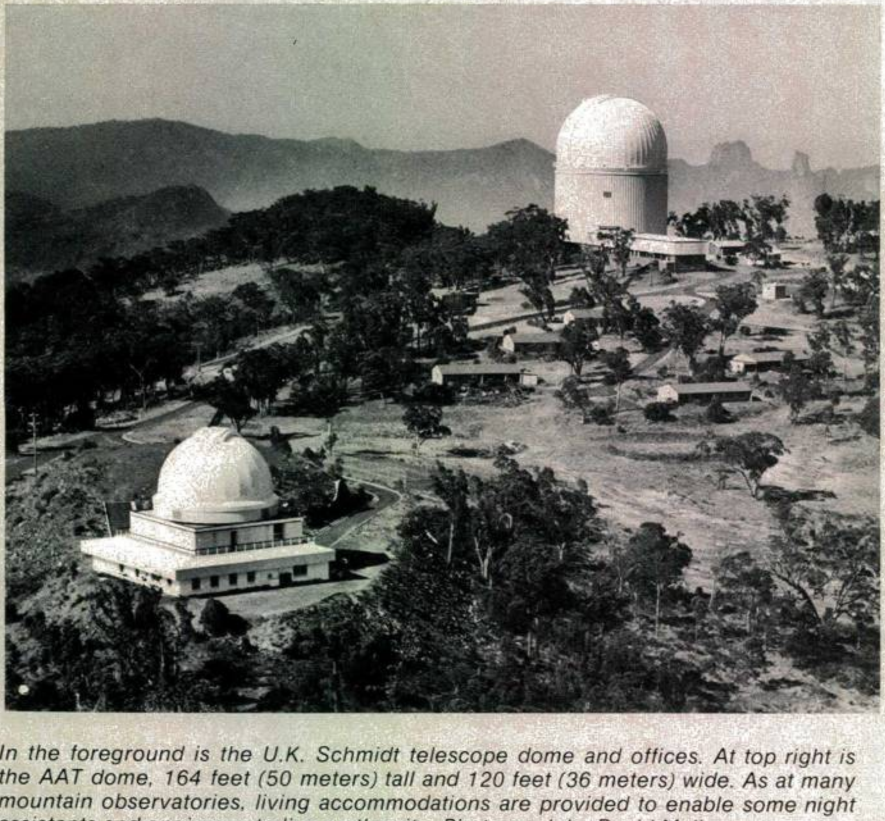
To get an idea of what the computer does, consider what happens when one observation, perhaps getting the spectrum of a star, has finished and a new one is to start. The telescope moves across the sky to the next star on the observer's list. The dome follows and is centered precisely over the telescope; the AAT opening is merely two feet wider than the telescope to reduce the effect of high wind. Both dome and 275 tons of moving telescope must be braked at the right moment to prevent them from overshooting the target. With the position of a new object programmed, an assistant presses the green start button. The telescope and dome are driven to their new positions in a minimal amount of time as two separate but simultaneous operations under computer control.

Within seconds the instrument zeroes in on the new object. Every factor affecting its apparent position, such as the bending of light in our atmosphere, telescope imperfections, and flexure in its structure, is automatically taken into account. In the brightly lit, air conditioned control room the astronomer and night assistant view the new object on a television screen. Final adjustments to the telescope are made manually, simply by looking at the star on the screen and guiding right onto it. The camera is then swung away and another observation starts under automatic control. Throughout the procedure the computer

AAT *continued on page 62*



The main frame of the 153 inch Anglo-Australian telescope is shown here supported by its massive horseshoe yoke. The total weight of this assembly is 335 tons. To the right and behind the telescope is the control room. At night shutters ensure that no light leaks from the control room into the telescope dome. Photograph by David Malin.



In the foreground is the U.K. Schmidt telescope dome and offices. At top right is the AAT dome, 164 feet (50 meters) tall and 120 feet (36 meters) wide. As at many mountain observatories, living accommodations are provided to enable some night assistants and engineers to live on the site. Photograph by David Malin.

AAT *continued from page 61*

issues a string of commands to adjust the telescope and keep the dome opening correctly over it. The computer also focuses the telescope by continuously monitoring the length of its tube relative to the length of an invar wire, which has negligible heat expansion properties. Meanwhile the astronomer studies the data as it comes in, in readiness for a decision on when to terminate the observation.

The impressive accuracy with which the AAT can point at a star required astronomers to change certain habits during the first year of operation. Rather than arriving at the telescopes with rough positions, intending to make final adjustments by eye, they are expected to furnish exact coordinates for program stars. This eliminates the need to spend perhaps 10 minutes coaxing the telescope onto its target star. On many other telescopes, especially smaller ones, this final adjustment process is unavoidable and must be done with care. On the AAT it would be a serious waste of valuable observing time.

Following commencement of regular scientific observations in mid-1975, much of the first 18 months were spent making observations with an image-dissector scanner. In conjunction with a spectrograph, this device records the spectrum of the light from a star or galaxy. The scanner replaces the conventional photographic plate. Instead of blackening an emulsion, the quantity of light in each part of the spectrum is electronically measured. This information goes to an instrument computer which displays the spectrum in real time — no waiting for the plates to be developed the next day — and permits preliminary data reduction.

Other instruments available include infrared photometers and a detector of radio waves with a wavelength of 2.6 millimeters (approximately .10 inch). In these modes the telescope observes in daylight because the sky at 2.6mm wavelength is no "brighter" by day than at night. By employing the AAT as a microwave radio telescope, astronomers have detected emission from the gas carbon monoxide in the Large Magellanic Cloud (the first discovery of molecules in this satellite galaxy of the Milky Way).

Five minutes' walk from the AAT dome is the UK Schmidt telescope, which is engaged in a photographic survey of southern skies that promises to be superior to the 20 year old Palomar Sky Survey. Night after night the Schmidt captures images of objects never photographed before. Particularly unusual findings can be followed up quickly on the AAT by suitable arrangement with the scientists scheduled to use it.

In its three years of operation, the AAT has revolutionized optical astronomy in Australia and Britain. There are numerous opportunities for scientists in both countries to work together, and also to follow up studies made by the large radio astronomy observatories at Parkes and Molonglo, New South Wales. But how is it decided who uses the AAT?

In both countries, a telescope observing committee meets every three months to consider AAT proposals. In Britain, demand exceeds supply by at least five times the 40 or so nights available in each quarter of the year. Yet this strong competition ensures that the scientific standard of successful proposals is very high. Approximately 10 projects are approved each quarter. Investigators are astronomers working in universities, or staff members of Britain's two Royal Observatories.

The telescope has made many discoveries. Perhaps its greatest achievement was in 1977 when astronomers detected faint flashes of light from the pulsar in the constellation Vela. Although radio astronomers have detected 100 of these pulsars, only one in the Crab nebula had previously been found optically. The Vela pulsar is far dimmer than the Crab pulsar, and is the faintest object ever recorded.

Much of the AAT "telescope time" has been spent on finding and studying hundreds of quasars. These beacons of the far universe are the most distant objects known. Light from remote quasars was already halfway through its journey to man's telescopes even before the sun formed.

Facilities such as the AAT are rolling back the frontiers of our universe at an unprecedented rate. The study of the quiet wheeling galaxies and peaceful starry realms has been revolutionized by discovery of many high energy phenomena. Quasars, pulsars, black holes and exploding galaxies now have the attention of professional astronomers, and have evoked wide public interest. *Simon Mitton.*

BRIEFS

- To meet a new agency ceiling of 23,237 permanent positions, NASA has been requested by the Office of Management and Budget to reduce its civil service personnel by 500 by the end of fiscal year 1978.
- One of the largest geological features in the deep sea — a spectacular V-shaped submarine canyon, 420 miles (700km) deep — has been discovered in the south Atlantic Ocean by a team of polar research scientists sponsored by the National Science Foundation.

Researchers Propose Brand X Supernova

The existence of a new, enormously powerful type of supernova has been proposed as part of a theory to explain quasars.

The new type of supernova, dubbed "brand X" by its inventors, Stirling Colgate and Albert Petschek of the New Mexico Institute of Mining and Technology, is an explosion that follows a collision between an ordinary star and a superdense neutron star.

According to Colgate and Petschek, "brand X" supernovae occur repeatedly in a quasar at a rate of 1 to 10 per year. Only at the center of a quasar, where millions of stars are packed into a small volume, do neutron star-ordinary star collisions occur this often.

The "brand X" supernova and the quasar theory was presented at an international conference in France in 1976. After introducing the "brand X" supernova, Colgate and Petschek described the processes that would convert the energy of the supernova into the infrared, optical and x-ray radiation that quasars emit.

There is no hard evidence that "brand X" supernovae actually exist, but Colgate and Petschek have a detailed theory about how they would work. The neutron star that collides with the ordinary star would, itself, have been formed in an ordinary supernova explosion. After collision occurs, the neutron star gradually dissolves as it spirals into the center of the ordinary star. The unstable configuration that results explodes after a short time as a "brand X" supernova. During the explosion, tremendous amounts of energy are released.

Colgate and Petschek discussed some of the advantages of their theory at the conference, including prediction of a steady mass outflow, similar to the observed outflows inferred from spectroscopic studies of the quasars. In two of the rival quasar theories, energy is derived from vast numbers of ordinary supernovae, or from the destruction of stars that are ripped apart by a massive black hole.

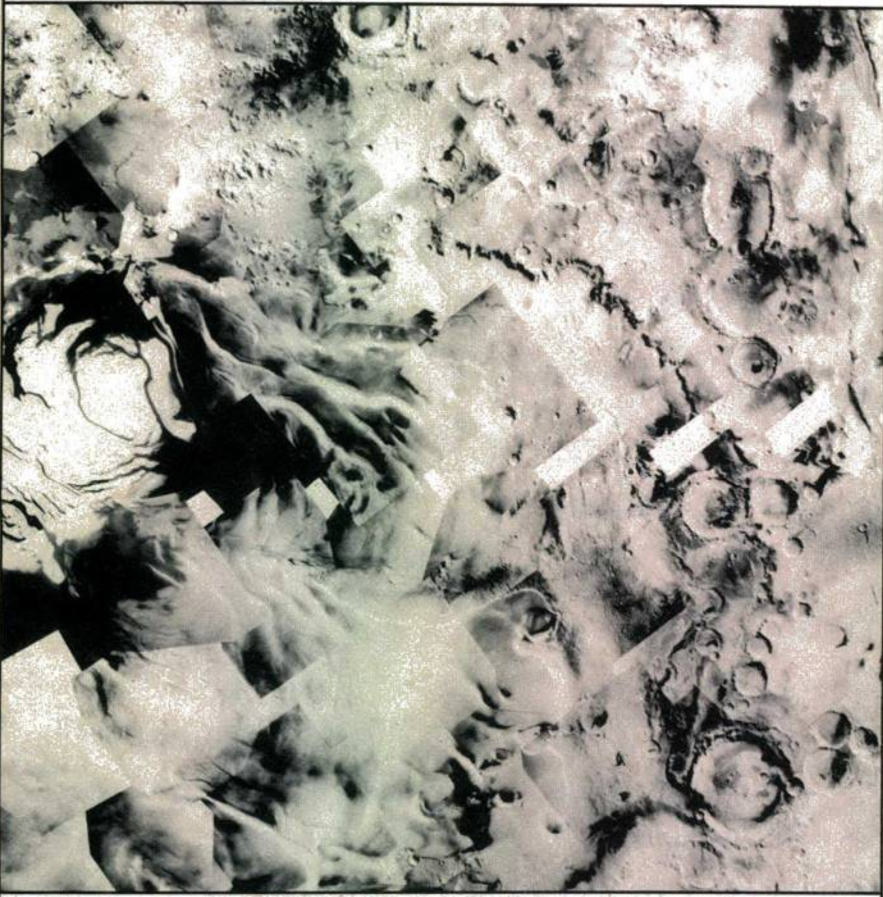
Constructing an intricate "brand X" supernova and quasar theory is a tricky business. The next steps to make the theory more rigorous will be difficult, since they will require complicated and expensive computer calculations. They will undoubtedly be carried out in the search for a solution to the nearly 15 year old mystery of quasars.

Radio Noise From Earth: Celestial Calling Card?

Somewhere in space, someone may be listening to CBS, NBC and ABC, as well as the other major television stations around the world. Extraterrestrials with a technological level similar to our own could detect TV broadcasts at distances of 25 light-years (a range encompassing about 300 stars), and would receive beams from our ballistic missile early warning radars at up to 250 light-years (a range encompassing several hundred thousand stars).

Scientists, including Britain's astronomer royal, Sir Martin Ryle, have previously urged that we keep our radio noise down to a minimum to prevent giving away our existence to potentially hostile extraterrestrials. According to astronomers W.T. Sullivan, S. Brown, and C. Wetherill of the University of Washington in Seattle, aliens eavesdropping on radio noise leaking from Earth could by now have put together a detailed picture of life on our planet, including an assessment of our defense capabilities. Their report was published recently in **Science**.

Summer on Mars



This mosaic, taken by Viking Orbiter 2 on Jan. 5, 1978, shows the south polar cap and surrounding area during the late summer season of Mars' southern hemisphere. The south pole is located just to the lower right of the bright white polar cap. During winter, the entire area shown in the photograph is covered by either carbon dioxide, water ice, or a mixture of both. The smooth, contoured terrain that occupies most of the lower left portion of the picture is a type unique to Mars' polar regions. It consists of many layers; the lack of cratering indicates recent origin. Erosion by winds coming from the south pole and curved counterclockwise by Coriolis force can be seen in the striations and pitting of the layered terrain. The origin of the layered deposits may be connected with global duststorms that occur every Martian year. NASA photograph.

Most of the radio noise leaking into space comes from North America and western Europe, where TV and radio transmitters are most numerous and powerful. Even more powerful than TV transmissions are beams from Ballistic Missile Early Warning System radars. An alien civilization with large radio telescopes may have its attention drawn first by these intense radar beams, and later be able to extract most information about life on Earth from our domestic TV broadcasts. Inhabitants of Alpha Centauri and points beyond would not, however be glued to their screens for weekly episodes of "Star Trek", because program information itself would be too weak to decipher over interstellar distances. But the aliens could receive the powerful carrier waves on which the programs ride.

By careful analysis of the Doppler shifts of the signals during a year, the alien civilization would be able to deduce the size of Earth's orbit around the sun and thus predict the likely temperature of our planet. This would reveal that we are probably air breathing, water drinking beings. They would also be able to measure the rotation rate, diameter, and axial tilt of Earth.

An estimate of the size of TV transmitting antennae would be possible from the size of their transmission lobes, thereby giving some indication of the scale of technological structures on Earth. This, along with knowledge of Earth's size, would enable the aliens to estimate the strength of our gravity and the likely size of a human.

A really curious extraterrestrial who listened, in turn, to each of the 2,000 or so most powerful TV transmitters on Earth could plot their positions to within a few miles, thus drawing a simple geographical map of our planet. Different broadcast schedules of various transmitters, combined with the locations of the early warning radars operated by the two superpowers, could reveal the political divisions of our planet.

NASA has announced plans to begin searching later this year for messages coming from other beings in space. If we are leaking as much radiation as the three astronomers say, NASA's radio telescopes might pick up a few calls asking us to turn down the noise.

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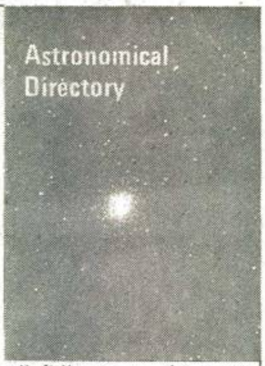

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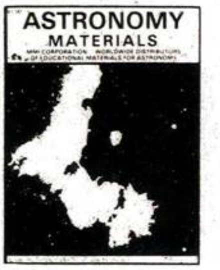

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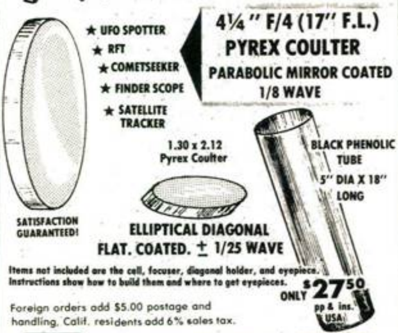

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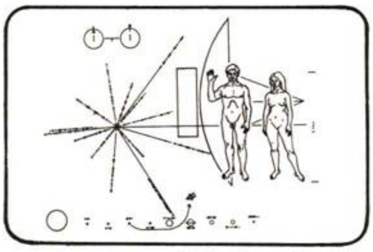

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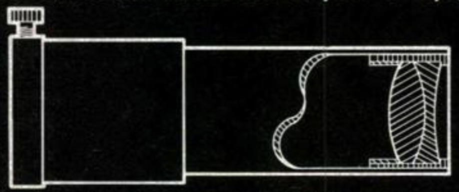

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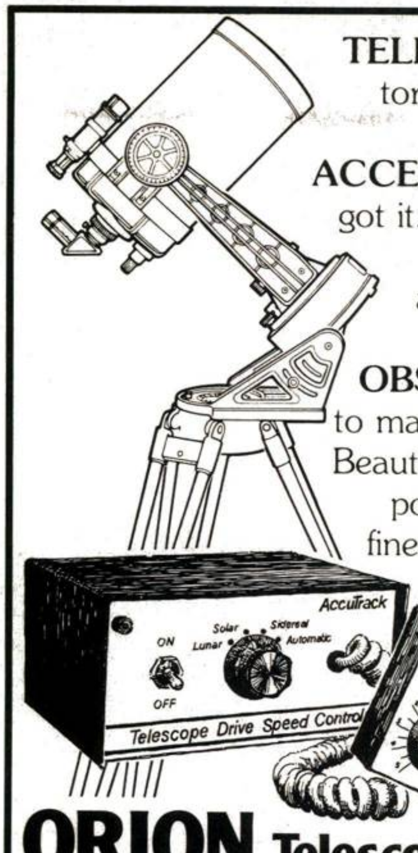

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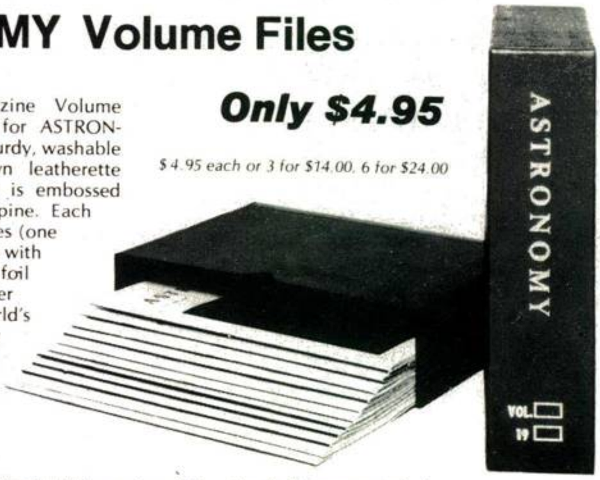

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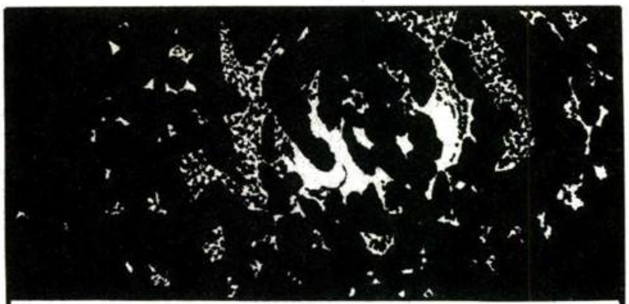

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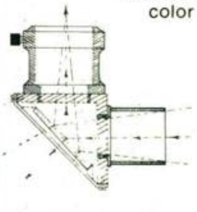

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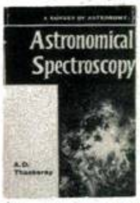

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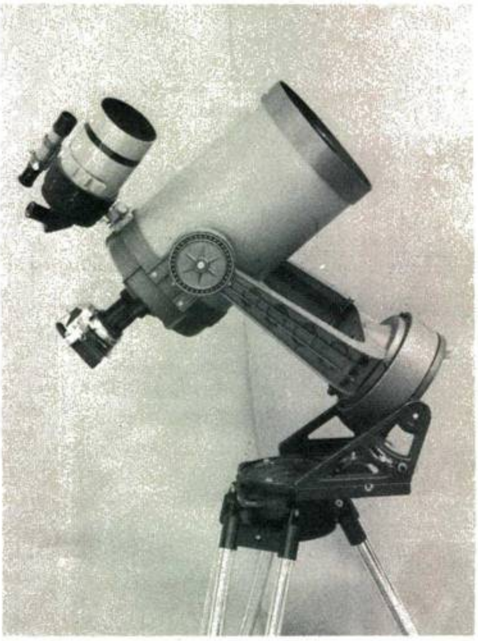

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by
James Mullaney and Henry J. Phillips

Far to the south on May and June evenings rises the constellation Centaurus the centaur. Little known or observed in midnorthern latitudes, Centaurus is the ninth largest of the constellations — and actually quite a bit of it rises above the southern horizon these spring nights. The visible portion, however, is mainly that which contains fewer bright stars; to see such sights as Centaurus' two first magnitude stars, Alpha and Beta Centauri (also called Rigil Kentaurus and Hadar), you have to travel to the extreme southern parts of the continental United States, to Hawaii, or below the equator.

If Centaurus is just barely visible, how is it that the constellation dates from Greek times? The answer is that, because of precession (a slow wobbling motion of Earth on its axis), the ancient Greeks could see more of Centaurus than we can today — including the stars that were later separated into the constellation Crux, the southern cross. Our sky is subtly different than the one the Greeks knew, and Centaurus and Crux are two casualties of precession that have been lost to us. On the other hand, a larger portion of the southern fall sky is visible to us: The Greeks, for instance, could only just see Fomalhaut when that star rose to its highest.

Centaurus represents a centaur, a figure unique to Greek mythology. No other ancient people seem to have invented this particular kind of half-man, half-horse (although the Babylonian cherubim, half-man and half-bull, came close). In Greek legend, centaurs were fierce and dangerous creatures, only partly civilized and easily angered.

Some idea of the wild and savage character of the centaurs can be had from the following myth. Peirithous, a member of the tribe of the Lapiths, married Hippodameia and invited as many guests as he could, including his cousins the centaurs, to the wedding feast. All went well until the wine was uncorked; the centaurs, unaccustomed to wine, were driven mad by its heady scent, and putting aside their sour milk, stampeded to the wine table. Soon, drunk beyond control, they began carrying off the female guests, with the worst of intentions. The Lapiths, of course, came to the women's defense, and Peirithous killed Eurytion, a centaur who was dragging the screaming bride into the bushes. From then on, the Lapiths and centaurs were the worst of enemies.

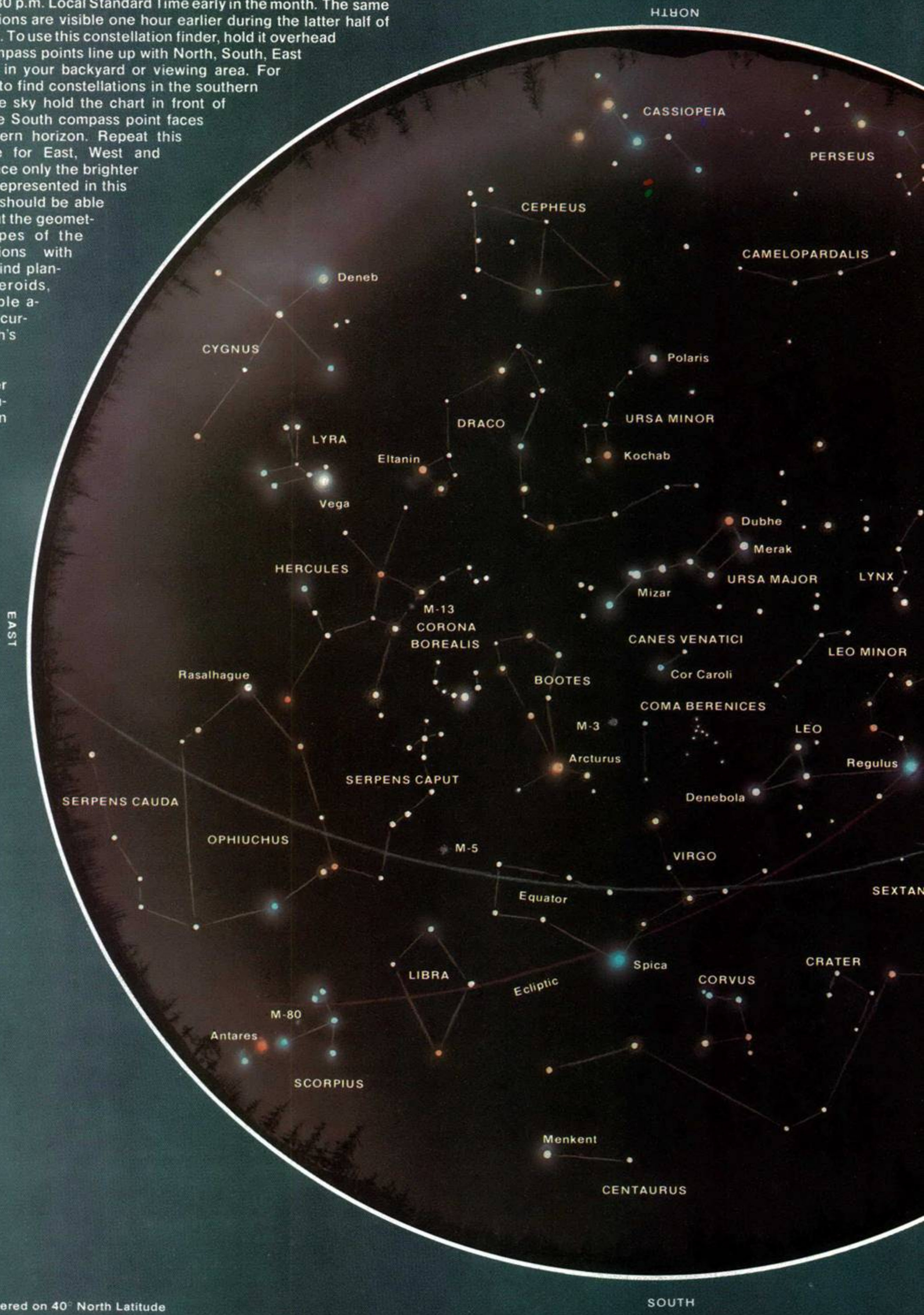
Most of the centaurs were as brutal and uncouth as the preceding story indicates. One who was not was Chiron (after whom astronomer Charles Kowal named his recently discovered "mini-planet"). Among the centaurs, he alone was immortal, and because of his great wisdom he served as tutor to many of the young Greek heroes, including Asclepius, Jason, Orpheus and Achilles. Chiron was honored by all the Greeks, gods and heroes alike, but was destined to lose his immortality at the hands of the greatest of Greek heroes, Heracles.

During the fourth of Heracles' 12 labors, the capture of the Erymanthian boar, Heracles stopped to relax at the cave of the centaur Pholus. To entertain his guest, Pholus opened the centaurs' communal wine jar and set a glass before Heracles. Unluckily, the wine was very strong; the other centaurs who were hunting nearby caught its scent and came galloping down to the cave in fury, determined to kill whoever was breaking into their wine stores (as they thought). Heracles defended himself with bow and arrow; since the arrows were poisoned with the blood of the Hydra (which Heracles had killed earlier and whose blood was fatal to the touch), all the centaurs who were hit by Heracles' arrows died in agony. But a poorly aimed arrow happened to strike Chiron in the leg. Since he was immortal, he could not die. But the wound did not heal, and after nine days of agony Chiron begged Zeus to let him die. Some say that Zeus transferred Chiron's immortality to Prometheus, the bringer of fire to man; others say that Castor, the mortal brother of Pollux, received the gift, allowing the brothers to remain together throughout eternity. In any case, Chiron died, and his figure was set among the stars as a constellation.

The question is, which constellation did Chiron become? There are two centaurs in the sky: In addition to Centaurus, Sagittarius the archer is always drawn as a centaur. Opinion is divided on the subject, but most choose Sagittarius to represent Chiron, while Centaurus is merely an anonymous wild centaur. Others write that Heracles placed Pholus in the sky, for that friend clumsily killed himself when he picked up one of Heracles' arrows, wondering how such a small weapon could wreak such havoc. Pholus dropped the arrow, which pierced his hoof and produced its usual poisonous effect.

But the centaurs ultimately had their revenge, for one of them was indirectly responsible for the death of the seemingly indestructible Heracles. Shorly after his wedding to Deianeira, the hero and his bride were returning home when they reached a river which, because of recent flooding, was impassable. Heracles knew he'd be able to cross, but what was to be done with Deianeira? While attempting to solve the problem, the centaur Nessus happened by and offered to carry the bride across the turbulent water on his back. Heracles accepted, but halfway across, he heard a scream from Deianeira and saw that Nessus, having safely carried her to the other side, was attempting to rape her. Heracles shot several arrows into the centaur's body, and the Hydra's poison once again proved fatal. But before dying, Nessus convinced Deianeira to save some of his blood in a vial, telling her it would prove an effective love charm should Heracles prove unfaithful. Deianeira, not knowing what might eventually come to pass, took Nessus'

This Star Dome rendering approximates the sky as it appears at about 10:30 p.m. Local Standard Time early in the month. The same constellations are visible one hour earlier during the latter half of the month. To use this constellation finder, hold it overhead so the compass points line up with North, South, East and West in your backyard or viewing area. For example, to find constellations in the southern part of the sky hold the chart in front of you so the South compass point faces the southern horizon. Repeat this procedure for East, West and North. Since only the brighter stars are represented in this map, you should be able to trace out the geometrical shapes of the constellations with ease. To find planets, asteroids, etc., visible among the current month's zodiacal constellations, refer to the planet finder on page **28**.


NORTH
EAST
SOUTH
CASSIOPEIA
PERSEUS
CEPHEUS
CAMELOPARDALIS
Deneb
CYGNUS
Polaris
DRACO
URSA MINOR
LYRA
Eltanin
Kochab
Vega
Dubhe
Merak
HERCULES
URSA MAJOR
LYNX
Mizar
M-13
CORONA
BOREALIS
CANES VENATICI
LEO MINOR
Rasalhague
BOOTES
Cor Caroli
COMA BERENICES
M-3
LEO
Arcturus
Regulus
SERPENS CAPUT
SERPENS CAUDA
Denebola
OPHIUCHUS
M-5
VIRGO
Equator
SEXTAN
CRATER
Spica
LIBRA
CORVUS
Ecliptic
M-80
Antares
SCORPIUS
Menkent
CENTAURUS

Map Centered on 40° North Latitude

Capella
AURIGA
GEMINI
Castor
Pollux
CANIS MINOR
M-44
CANCER
Procyon
WEST
MONOCEROS
HYDRA
Alphard

Map by Adolf Schaller

advice and kept the vial a secret from her husband.

We can imagine Deianeira sitting neglected at home over the next few years while Heracles went gallivanting all over the Greek countryside, having one adventure after another. Finally, however, her patience came to an end when Heracles razed the town of Pechalia to win the hand of the princess Iole. Deianeira, understandbly loath to share her husband with another woman, remembered the blood of Nessus. She rubbed it into a newly woven shirt and sent it via messenger to her husband, secretly congratulating herself on the ease with which she was able to win Heracles' affection back. It was only when the messenger was long gone that Deianeira saw the tuft of wool she had used to rub the love potion into the shirt blazing on the flagstones where she had dropped it. The "love charm" was in reality a burning poison. Sure enough, when Heracles put on the shirt, the flames ate into his skin; when he tried to remove it, it tore away his flesh. After killing the messenger, Heracles sent for Deianeira to punish her, but it was too late: She had hanged herself! Finding no relief from the poison, Heracles built his funeral pyre and burned away his mortal part; the immortal part was taken up to Mt. Olympus by Zeus. Just before his death, Heracles gave his Hydra-poisoned arrows to his nephew Philortetes, in whose hands they proved a great aid in ending the Trojan war.

Close-Up

Eastern Hydra/Northern Centaurus Region

Our Close-Up region for this month extends from 13 to 15 hours of right ascension and from -22 to -50 degrees declination — an expanse occupied by the eastern ramparts of Hydra and the northernmost portion of Centaurus. The mere mention of such southerly celestial regions is frequently enough to scare off an otherwise dedicated deep sky observer. For some reason, a kind of psychological block immediately sets in that may keep someone from enjoying the many wonders to be found between the celestial equator and the visible horizon.

To be sure, there are difficulties attending low altitude telescopic exploration. Atmospheric absorption, for one, results in an extinction factor of several magnitudes near the horizon — not to mention the frequent buildup of clouds and haze there, due to the perspective involved. In addition, multiple turbulence often produces severe scintillation (poor seeing or image steadiness), and refraction by the atmospheric "lens" causes a prismlike dispersion of images here (which, for a bright star, can be a spectacular sight in itself!). But rather than give up in the face of such conditions, why not accept them for the challenge they represent, and keep trying? As with planetary observation, that moment when the air suddenly "clears" and you catch sight of an object in all its glory is worth all the waiting involved.

Despite its limitations, stargazing in southerly precincts like this month's region can be a rewarding experience — even with only a small telescope. For best results, observe *south* of the town or city in which you live, thereby placing the glow of its lights behind (north of) you. It's also important to survey objects as they transit the meridian (north-south line passing through the zenith overhead), for they will then be at their maximum elevation above the horizon. Residents of the southern U.S. will have an easier time here, as the objects discussed reach higher elevations the farther south you go.

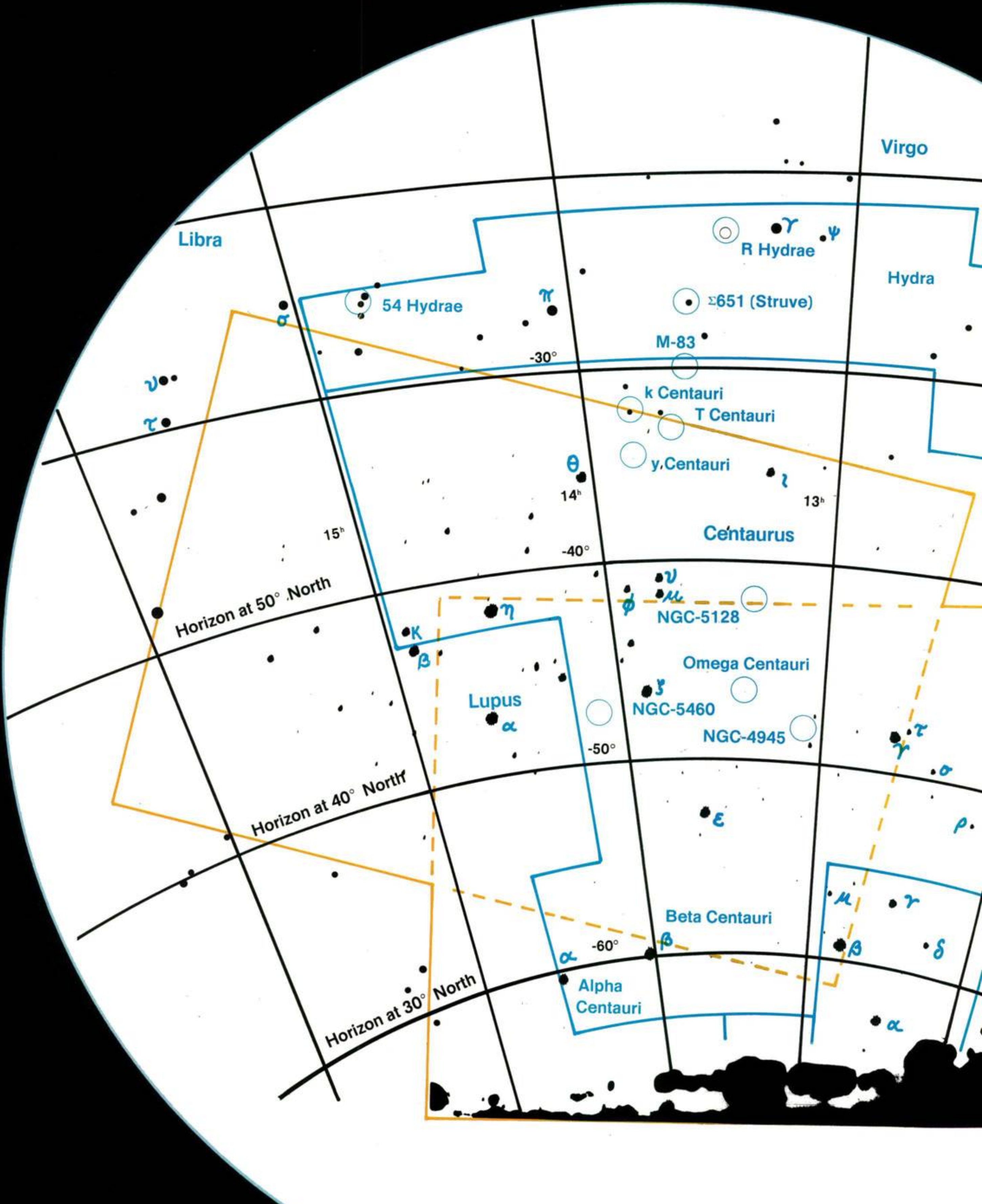
Hydra is the largest (and longest) constellation in the entire heavens, covering more than 1,300 square degrees of sky area. Its middle and western sections have already been highlighted in past installments of Star Dome (May 1975 and March 1977). Centaurus is perhaps best known for its brightest star, Alpha (α) Centauri — the famous triple star system whose faint member Proxima is our nearest known stellar neighbor. Alpha, and Centaurus' other first magnitude star, Beta (β) Centauri, lie some 10 degrees below our -50 degree declination limit, but Centaurus contains a sufficient number of striking sights north of this limit that make it worth investigating.

Many writers, including Olcott and Brown, bypassed this month's region entirely in their works. Webb did not include Centaurus but did treat Hydra, introducing it as "a very lengthy and not very interesting constellation to the unaided eye; but containing some telescopic work". Others considered Hydra an obscure group and poorly stocked with objects for its great size. Nevertheless, there's a lot to see and do here!

Before commencing our telescopic journey into this cosmic southland, there is a significant fact that you may note by way of encouragement: Messier was able to pick up the spiral galaxy M-83, at its declination of nearly -30 degrees, from his observatory in Paris. This happens to be farther north than the latitude of Montreal, Canada — and higher than that of the majority of our readers! It *is* possible to do worthwhile observing of southern precincts from northern locations!

R Hydrae

Beginning at the "top" (the northern edge of Hydra) and working our way downward in the sky, our first stop is a


Virgo
Libra
R Hydrae
Hydra
54 Hydrae
Σ651 (Struve)
M-83
-30°
k Centauri
T Centauri
y Centauri
14h
13h
15h
Centaurus
-40°
Horizon at 50° North
NGC-5128
Omega Centauri
Lupus
NGC-5460
NGC-4945
-50°
Horizon at 40° North
Beta Centauri
-60°
Alpha Centauri
Horizon at 30° North
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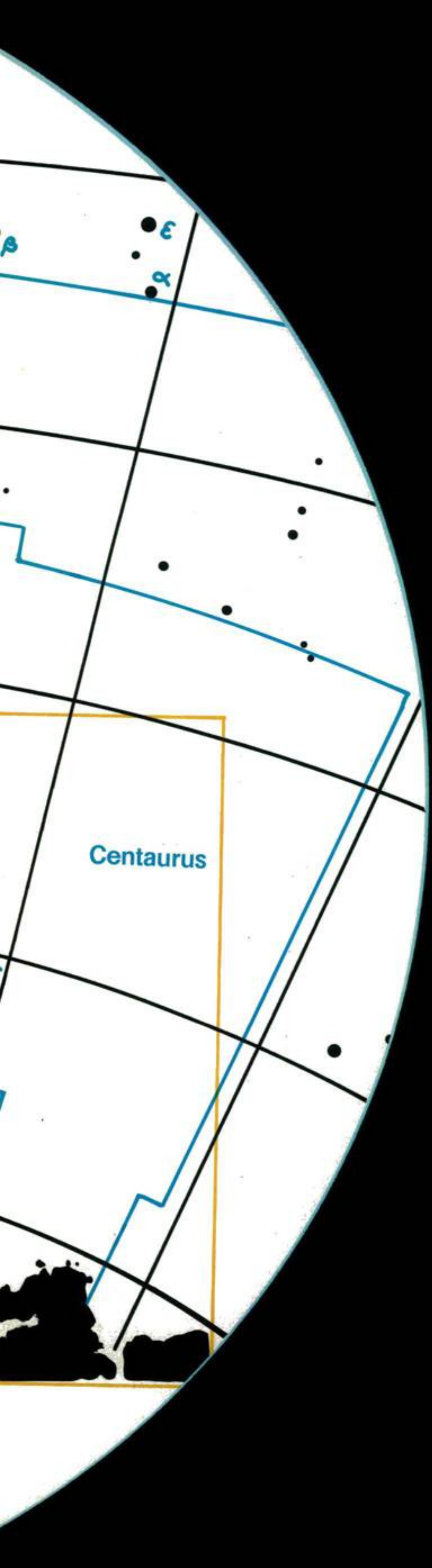
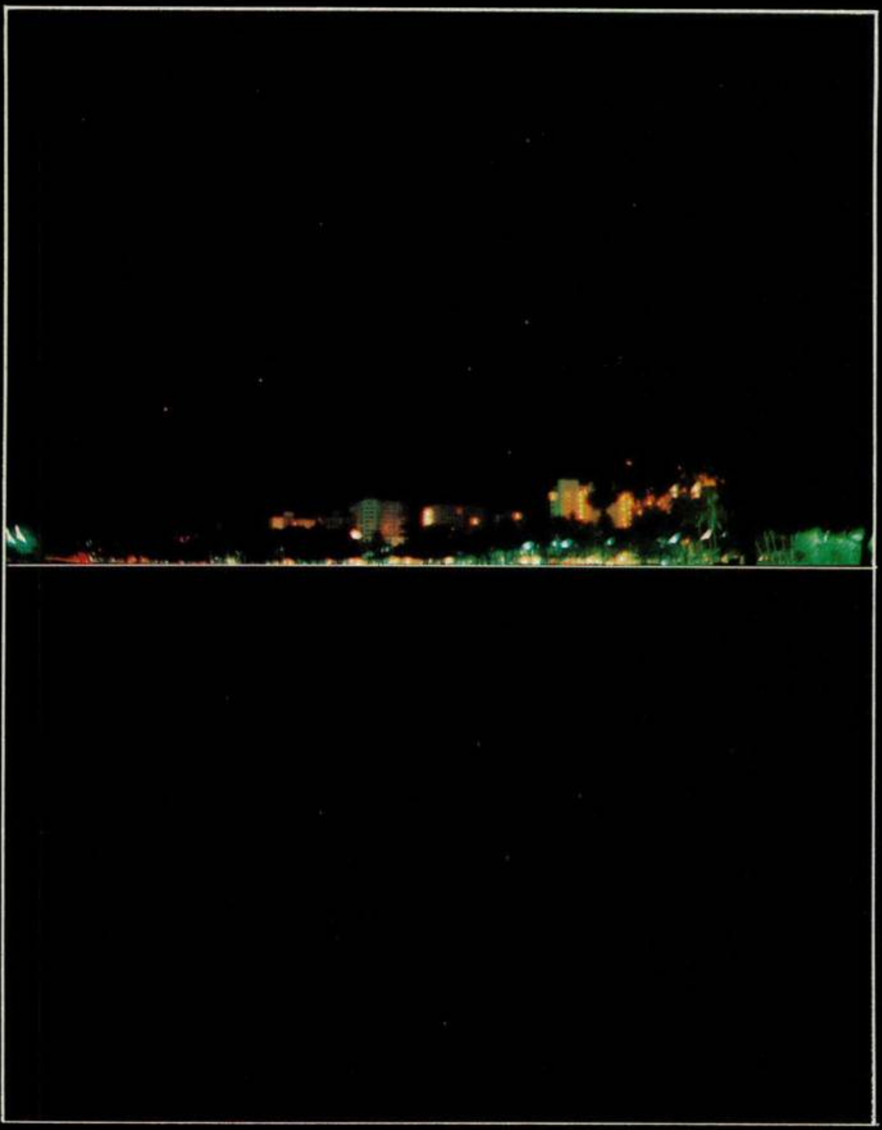




This month's Star Dome map is the result of California's unusually rainy weather. ASTRONOMY's faithful contributing photographers, Brad Wallis and Bob Provin, thwarted by rains, closed and washed-out roads, and perpetually cloudy skies, were unable to photograph the Centaurus/Eastern Hydra region. Presented instead this month are two short exposure photographs taken in Hawaii — the ultimate location for southern style observing from United States soil. Lights in the foreground are those of Honolulu. Next month Star Dome will return to its usual format. Photographs and map by Richard Berry.

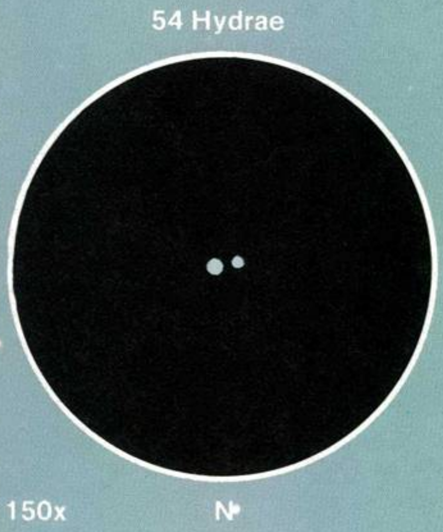
fiery red variable star — one that at times can be seen with the unaided eye and on other occasions needs a small telescope to be glimpsed. This is R Hydrae, situated two degrees due east of third magnitude Gamma (γ) Hydrae. Both objects lie near the Hydra-Virgo border south of the first magnitude star Spica (which incidentally serves as a convenient guidepost for all of this month's region).

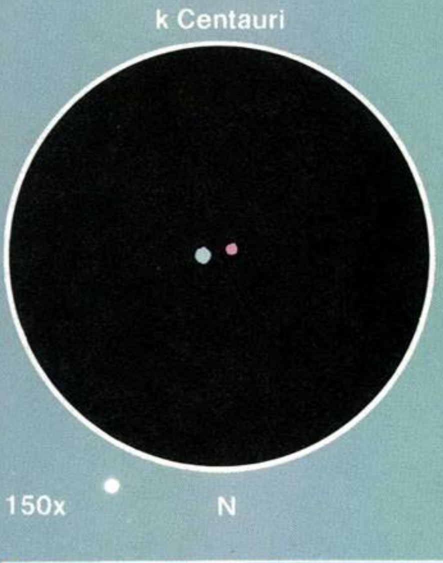
This pulsating interstellar beacon is a long period Mira Ceti-type variable whose light cycles from 4th to 10th magnitude in just slightly more than a year. A giant sun of spectral class M7, R Hydrae has a warm cast to it throughout its entire magnitude range as seen in a three or four inch telescope. Barns listed it without comment, while Espin described it as being a "splendid red" in hue. Webb gave the period as 469 days and made the interesting remark that it was "diminishing". In later editions of his work, it was noted as 425 days. The accepted value today is 386 days. Were the earlier figures in error, or has R Hydrae stepped up its pulsations?

54 Hydrae

The next item on our celestial bill of fare is an attractive double star designated 54 Hydrae. Look for it atop a vertical chain of naked eye stars (58, 57, 56, 55 and 54 Hydrae) at the Hydra-Libra border. This group lies some eight degrees east of third magnitude Pi (π) Hydrae.

Here we find a fifth magnitude primary and seventh magnitude companion about nine seconds of arc apart near position angle 128 degrees. This pair is a fine sight in a three inch refractor at 45 power and a marked color contrast is evident, as our drawing made from a six inch reflector at 150 power shows. Smyth called the brighter star deep yellow and its attendant reddish violet. Bernhard, Bennett and Rice gave the tints as red and blue, while Muirden logged them as yellow and bluish.





The vivid yellow-violet pair 54 Hydrae sparkles and scintillates on nights of poor seeing, but on good nights you'll have no problem splitting this southern gem. Both components of k Centauri shine a brilliant blue-white, characteristic of hot young stars. Separated by eight seconds of arc, even the smallest scope can reveal this pair's duplicity. Drawings by James Mullaney.

54 Hydrae appears on at least one old roster of the finest colored double stars (that compiled by Colas in the 1890s), where the hues were noted as yellow and violet. Both Webb and Barns included this object in their books — but without descriptive comment. The latter did remark, however, that the sky here contains "a legion of vari-tinted multiples, quite bewildering though low in our latitudes".

M-83

The only Messier entry in this region — but one that happens to be something of a showpiece within its class — is the large broadside spiral galaxy M-83. Although visible in a large finder or binoculars, guide stars are scarce here; you'll pick up this object most easily by sweeping with a low power eyepiece on the telescope itself. You'll find it lurking roughly midway between the stars Gamma Hydrae (third magnitude) and Theta (θ) Centauri (second magnitude).

M-83 measures at least 10 by 8 minutes in apparent size, and some observers make it even larger in extent. Its visual brightness is somewhat uncertain; although generally given as about 10th magnitude, it is definitely much brighter than this. Recent determinations place it somewhere between seventh and eighth magnitudes. As Flammarion long ago pointed out, this object is certainly among the brightest of the galaxies.

Many of the classic observers, including Webb and Barns, bypassed this fine extragalactic specimen. Mysteries abound in this area; Barns, for example, did include and describe NGC-5061, a faint 12th magnitude elliptical just five degrees from M-83 itself. Pickering considered this Messier object unworthy of entry in his "best sky objects" roster, despite the fact that he observed from Jamaica with an 11 inch refractor!

In its coded form of description, the NGC gives M-83 a double exclamation mark (!!), which translated means "remarkable — very much so". Bernhard, Bennett and Rice noted it as "A triply branched spiral nebula in Hydra. Called by John Herschel very bright, very large. Nuclear condensation near center, and the entire nebula of S-shape backward." Holyoke remarked ". . . fairly bright and would be easy if it were farther north. At its low altitude during a time of year when hazy skies are frequent, good views are not easy to come by."

Even a three or four inch telescope at 45 power will show M-83 nicely on a dark night, and this remote star city looms large in 6 to 10 inch instruments at 100 power or more. There is a well-marked nucleus, and attentive scrutiny will reveal definite spiral structure in moments of steady air. Recent distance estimates place this island universe at 8,000,000 light-years from us.

Selected Objects — Eastern Hydra/ Northern Centaurus Region

Object	Type	Mag.	Size/ Sep.	R.A. (1950)	Dec.
HYDRA					
* R Hydrae	V:386^d	4-10	—	13^h27^m	-23°01'
ϵ651	★2	5.5,7.0	11"	13^h34^m	-26°14'
* M-83	SG	7.5	10'x8'	13^h34^m	-29°37'
* 54 Hydrae	★2	5.2,7.1	9"	14^h43^m	-25°14;
59 Hydrae	★2	6.4,6.4	0.7"	14^h56^m	-27°27'
CENTAURUS					
NGC-4945	SG	9.5	12'x2'	13^h02^m	-49°01'
* NGC-5128	PG	7.5	10'x8'	13^h22^m	-42°45'
* ω(Omega-NGC-5139)	GC	3.7	23'	13^h24^m	-47°03'
T Centauri	V:91^d	5.5-9	—	13^h39^m	-33°21'
* k Centauri	★2	4.7,6.2	8"	13^h49^m	-32°45'
y Centauri	★2	6.4,6.4	0.9"	13^h51^m	-35°25'
NGC-5460	OC	6.3	30'	14^h04^m	-48°05'

* Detailed in Close-Up

★2 = Double Star
V:#d = Variable Star, period
OC = Open Cluster
GC = Globular Cluster
SG = Spiral Galaxy
PG = Peculiar Galaxy
Mag. = Magnitude
Sep. = Separation

k Centauri

Proceeding southward now into Centaurus, we encounter another striking double star for small telescopes. This is k (also designated 3) Centauri, one of a vertical chain of naked eye stars that includes z, g and h Centauri, northwest of Theta Centauri. To distinguish k from the others, look for a matching sun (l Centauri) just west of it.

This duo consists of 4.7 and 6.2 magnitude blue-white suns eight seconds apart in position angle 110 degrees, as shown in our drawing with a six inch reflector at 150 power. Even a two inch scope at 30 diameters splits them nicely on a steady night. Their respective spectral types are B5 and B8, indicating that they are highly luminous, hot young stars. We view this slow moving binary from a vantage point of some 470 light-years.

NGC-5128

Our final two selections both lie very

nearly on the same parallel of right ascension as does Spica, which therefore serves as an ideal indicator of the best time for seeking them out. When Spica stands on the meridian, you will find them waiting some 30 degrees directly south, just above the horizon.

Higher of the two is the mysterious galaxy HGC-5128, located at a declination of nearly -43 degrees — six degrees due south of third magnitude Iota (ι) Centauri. Binoculars will show it and are good for identifying its position in relation to surrounding stars. It is catalogued as the same size and brightness as M-83 — 10 by 8 minutes of arc and about 7.5 magnitude, and again is among the brightest galaxies in the sky.

Both on photographs and as seen visually in medium sized telescopes, NGC-5128 looks very much like an edge-on spiral with a dark obscuring rift about its middle — similar to the well-known Sombrero galaxy, M-104 in Virgo. Originally classified as an irregular galaxy by Hubble, Shapley and others, it is regarded as a "peculiar" elliptical system by most authorities today.

Astronomers Robert Jastrow and Malcolm Thompson have vividly described this unusual state of affairs as follows: "This object presents one of the strangest appearances in the sky. A luminous body, looking like normal elliptical galaxy, is bisected by a broad lane of dark matter. The dark lane was once thought to be a spiral galaxy, viewed edge-on, in the process of collision with the elliptical galaxy behind it. It is possible instead that NGC-5128 is a single galaxy that has suffered an explosion at its center, with the consequent ejection of fast moving material out to space. An adequate explanation of the nature of this very unusual object has yet to be given."

Other indications of violent activity occurring within this object include the fact that NGC-5128 is a source of intense radio emission (and is therefore also known as Centaurus A), as well as x-rays. The size of its optical image as determined from observatory photos has been found to be more than *twice* the figures given above — 23 by 20 minutes — and a faint optical "jet" has recently been discovered.

As is to be expected, this object is missing from most of the classic observing guides due to its low altitude. From the southern hemisphere it ranks as a real showpiece, although apparently Pickering overlooked it completely in his survey. The NGC describes it as "Remarkable — very much so. Very bright, very large, very much extended (in position angle) 122.5 degrees, bifurcated."

Although a deep southern object, NGC-5128 is still well worth the search, especially just after the air has been swept clean by a passing front and stars can be seen near the horizon. A four inch RFT at just 15 power shows it nicely, but from northern latitudes, at least an eight inch is needed to fully appreciate this weirdly beautiful galaxy. Appropriate to its enigmatic nature is the fact that its distance from us is also a mystery; virtually all lists in which NGC-5128 is included choose to leave that column blank!

Omega (ω) Centauri (NGC-5139)

We conclude this month's survey with a magnificent globular assemblage of stars so bright that it was assigned a Greek letter in its host constellation as a naked eye star! This is NGC-5139, better known as Omega Centauri. It is located four degrees due south of NGC-5128, 10 degrees south of Iota and 36 degrees south of Spica. At its declination of -47 degrees, it lies just three degrees above the horizon at latitude 40 degrees north (atmospheric refraction elevates it slightly higher than this amount). From more southerly latitudes, of course, it rises higher.

With an integrated visual magnitude of 3.7 and an apparent diameter of at least 23 minutes of arc, this object is generally regarded as the largest and brightest of all globular clusters. From southerly latitudes — from Hawaii, for instance — it appears as a hazy star without any optical aid and can be partially resolved at the edges in high power binoculars! Most of our readers will find they need an unobstructed horizon, a dark transparent night, good seeing and at least an eight inch telescope to begin to appreciate its full splendor.

Like NGC-5128, Omega Centauri is absent from most guidebooks — except perhaps for secondhand narratives based on the accounts of those who have actually seen it. The visual observer who probably devoted the most attention to this cluster's features was Sir John Herschel, during his expedition to the Cape of Good Hope for the purpose of extending his father's surveys to the southern sky. Following is a sampling of his impressions of this stellar beehive as viewed in an 18.8 inch metal mirrored reflector:

"The richest and largest object of its kind in the heavens . . . the stars are literally innumerable . . . . Cluster of full 20 minutes, thousands of stars magnitudes, 12 and 13 only, or 13 and 15; the larger (brighter) like lacework, two darker spaces in center . . . . All clearly resolved into stars . . . . This most glorious object fills the whole field with its most condensed part, and its stragglers extend 3/4 of a field beyond it either way. It is very conspicuous to the naked eye as a dim cometic looking star, fourth or fifth magnitude." Surely Herschel's tantalizing accounts are enough to make any star lover want to book the next southbound flight to see such majesty for himself!

The NGC rates Omega Centauri "a magnificent. . . object". Norton called it "A noble globular cluster. Like a tailless comet, nearly fourth magnitude to the naked eye . . . 30 minutes in diameter and contains thousands of 12th and 15th magnitude stars." Other descriptions can be found, but words fail to convey the indescribable and overwhelming beauty of celestial showpieces like this one.

Perhaps the only observer not overly impressed upon seeing Omega Centauri with his own eyes was, again, Pickering. It almost seems he grudgingly included it in his listing, for he stated: "a somewhat overrated object. Very large, and stars very numerous, but extremely faint. It might rank higher if seen with an aperture of the largest size." This despite the fact he was viewing it with an 11 inch telescope from the superb skies of the West Indies!

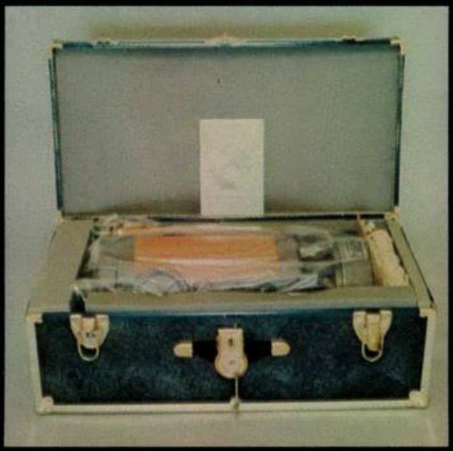
Astronomer T. Schmidt-Kaler has found the diameter of this cluster from long exposure photographs to be more than one degree (65 minutes) or two full moons in extent, and places it at about 17,000 light-years from us. Another cluster specialist, Helen Sawyer Hogg, placed it somewhat nearer at 15,000 light-years. In either case, Omega Centauri ranks as one of the closest globulars.

We can only imagine the view greeting any inhabitants of planets located near the center of this glorious orb. Some speculate that, with the stars so numerous and just fractional light-year distances apart, it would never get dark! Others calculate that the collective light of so many suns (perhaps millions) would equal that of several thousand full moons — illumination matching that of terrestrial twilight. Globular clusters were among the earliest parts of the galaxy to form, and they contain some of the oldest stars known. Civilizations existing there could be millions or even billions of years in advance of our own. On the other hand, recent studies indicate that stellar collisions may be a frequent occurrence in some densely packed globulars, which may mean relatively short planetary lifetimes in their cores.

Such imaginative speculation is both proper and rewarding in viewing the cosmic scenes before you at the eyepiece. Try placing yourself "there" — this transforms observing from a purely visual sensation to a mind-expanding adventure! In so doing, you will be in good company, for it was Albert Einstein himself who stated: "Imagination is more important than knowledge."

Celestron 8 Schmidt-Cassegrain Telescope

Background Photo
Andromeda Galaxy Taken With Celestron 8



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